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Laboratory Experiments in Psychology

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in Psychology

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PREFACE

The laboratory exercises in this book have been used in an introductory course in psychology at Harvard University during the past four academic years. We have tried to achieve two goals in the teaching of psychology with these experiments. First, we hoped to give our students some first-hand experience with the quality of a psychological fact. The generalizations and principles encountered in a text, no matter how excellent, cannot communicate the degree of certainty nor the aura of doubt that characterizes the empirical substance of our science. Rather than ignore this important aspect of psychology in an introductory course, we chose to let the student come upon it by himself. Second, we have tried to enrich the student's understanding of a selected group of experimental discoveries by giving him the opportunity for rediscovery. For the second goal, much more than for the first, the selection of experiments is crucial, and it is surely open to criticism and disagreement. Considerations of expense, practicability, and personal predilection have operated upon us and have, certainly, influenced our choice of experiments.

Our personal predilection may seem most idiosyncratic in regard to statistical technique. Our book, unlike most others of its kind, uses only a few descriptive statistics. It was, however, our intention that the work in the book be within the grasp of students with no special preparation either in psychology or statistics, and so we have tried to choose experiments for which the results would be clear-cut enough to be detectable without the aid of sampling statistics. Although our intention limited the range of possible experiments, it also extended the range of students who might do them.

Most of the experiments call for equipment easily assembled in the typical department of psychology with the aid of ordinary hand tools. The more elaborate pieces of apparatus, like memory drums, tachistoscopes, and recording galvanometers, if not already available, may be purchased from commercial apparatus companies. No attempt was made to list the names of these commercial suppliers, since we felt that for the purposes of the book virtually anything found on the market would suffice. The paper-and-pencil materials used in the experiments are included in the book, with the exception of the nonsense-syllable lists for Chapter 13, which are omitted so that the students in the course may use each other as experimentally naïve subjects. (For this experiment, the instructor should provide lists of typical consonant-vowel-consonant syllables.) For the recording of data, a packet of ruled papers with special coordinates (for example, logarithmic and probability) is attached to the back cover. We have assumed that ordinary linear paper is easily obtained and would, therefore, unnecessarily contribute to the bulkiness of the book.

We wish, finally, to express our gratitude to the numerous people who have contributed to the book: the students who have taken our course and have shaped our notions about the instructional laboratory by what they learned and failed to learn, and the teaching fellows who have each year supervised the laboratory sections and have thus put our notions to the test. We thank Ralph Gerbrands and George Silkwood of the machine shop in the Harvard Psychological Laboratories for their patient and skillful translation of our imprecise instructions into useful and inexpensive apparatus.

Cambridge, Mass. J. C. S.
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June 1965

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Laboratory Experiments in Psychology

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1

The Temperature Senses

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INTRODUCTION

As a sense organ the skin mediates a variety of sensations, such as pressure, pain, cold, and warmth. Is the skin to be thought of as a single sense organ capable of responding differentially to different classes of stimuli, or is it rather to be thought of as housing a number of small sense organs or receptors, each responding to its appropriate class of stimuli and giving rise to a particular sensory quality? One experimental, if somewhat indirect, approach to this question, already used extensively in the nineteenth century, is to probe the skin in a punctiform manner; that is, small areas of the skin are stimulated by one or another kind of stimulus, and the observer reports whether or not a given kind of sensation is aroused.

This kind of experimentation has revealed that the skin is not uniformly sensitive. For example, a heated rod touched to the skin will evoke a sensation of warmth at some spots but not at others. For the threshold sensation of pressure, it is necessary to exert many times more pressure on the back of the forearm than on the fingertip, and so on.

The objective of the present experiment is to determine the relative sensitivity of a portion of the skin to punctiform stimulation by cold and warmth. The purpose is to learn whether cold and warmth sensitivity are independently distributed on the skin and whether "maps" of cold and warm "spots" are relatively reproducible from one time to another.

For additional information see Chapter 10 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

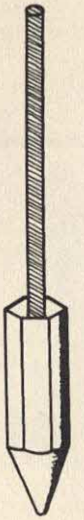

FIGURE 1-1. A temperature cylinder, milled from brass, into which a wooden handle is inserted.

APPARATUS

Warmth and cold will be applied to small portions of the skin by means of brass cylinders (usually called "temperature cylinders") that have a diameter measure of approximately 1.5 mm and taper at one end to a flat surface (see Figure 1-1). These cylinders are cooled or heated in constant temperature water baths (Figure 1-2).* For cold, the bath can be simply ice water, preferably kept in agitation by an electric stirrer. For warmth, it is convenient (but not necessary) to use a thermostat (set at about 40°C) to control a heating element in an agitated bath. The temperature of these baths should be continually checked throughout the experiment. The heat capacity of a brass temperature cylinder is large enough to permit its use for about a minute outside the bath, but it is a good idea to keep at least two cylinders in the bath and to switch from one to another after every few stimulations of the skin.

PROCEDURE

The students should work in pairs, alternating as subject and experimenter. Clean vigorously and, if necessary, shave the back of the hand and apply to the skin an inked stamp that forms a grid of lines spaced about

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*An alternative and somewhat cheaper method of stimulation is given by Woodworth and Schlosberg, *op. cit.*, p. 275.

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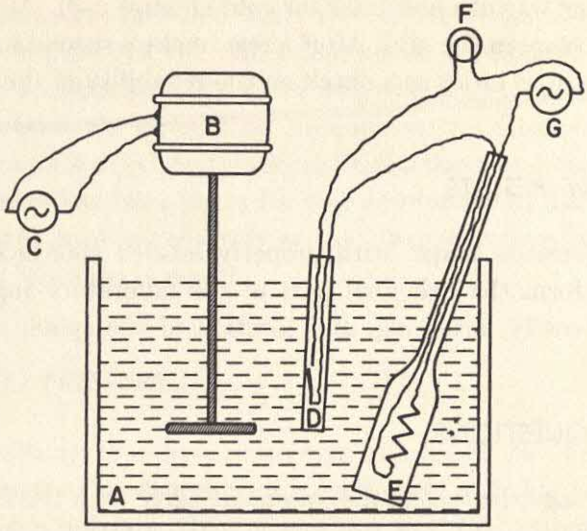

FIGURE 1-2. The components of a constant-temperature bath: (A) a glass container; (B) a motor-driven stirrer connected to a voltage source (C); (D) an immersible thermostatic switch wired in series with (E) an immersible heating coil; (F) a light bulb to monitor the action of the thermostat. The bulb also serves to regulate the heating rate of the bath (the larger the wattage of the bulb, the greater the heat produced by the coil); and (G) the connection to the wall voltage supply.

2 mm apart. (The same stamp can be applied to a sheet of paper for recording the responses of the subject.) Before starting the actual mapping it is absolutely essential to practice applying the cylinders and making the judgment. The stimulators should be dried quickly before use and applied very briefly and with very light pressure. In the practice period, the experimenter should learn to apply the stimulus in a uniform way from one trial to another; the subject should try to acquire a stable criterion for making the judgment. Choose an area of approximately 1.5 by 2.5 cm and map

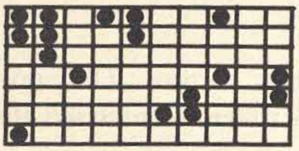

FIGURE 1-3. A grid showing spots that elicited a report of "cold."

the area first for warmth and later for cold (Figure 1-3). Apply the stimulator to each square in the grid. After a rest, make a second map for the two senses in the reverse order as a check on the reliability of the measurement.

TREATMENT OF RESULTS

The temperature maps, with properly labeled coordinates for future identification, form the principal part of the laboratory report. Compare the number, density, grouping, and location of the spots.

DISCUSSION QUESTIONS

How well does the second measurement agree with the first? How does the outcome bear on the question of the independence of the two thermal senses? In what respects do the results confirm or depart from the usual finding? In what ways does the experiment help to clarify the nature of a cutaneous "spot"?

Among other things, the absolute number of spots obtained will depend, of course, on the temperature of the stimulus and on the part of the body that is stimulated. If there is time, these factors may be profitably studied in an appropriate experiment.

THERMAL ADAPTATION

With very little extra effort, it is possible to observe the phenomenon of thermal adaptation in this laboratory session. Prepare a water bath whose temperature feels approximately neutral to the hand (in the vicinity of 32°C) and another bath whose temperature is about 16°C and feels cool. Immerse one hand in the 16° bath, the other hand in the 40° bath until both baths feel neutral. Then place both hands in the neutral bath and compare the sensations in the two hands. Approximately how long do the effects of adaptation linger? Include a brief account in the laboratory report.

"SYNTHETIC" HEAT

For this demonstration a "temperature grill" is used. The apparatus consists of two sets of alternating tubes. Cold water is circulated through one set and warm (but not hot) water through the other set. The inside of the forearm is touched to the grill under three conditions: (1) when only the cold water is circulating, (2) when only the warm water is circulating, and (3) when both are circulating simultaneously. Observe the surge of apparent heat aroused by simultaneous stimulation by warmth and cold. What explanation has been given for this phenomenon? Does it have any theoretical significance in the study of the thermal senses? Include a brief account in the laboratory report.

SENSITIVITY TO PRESSURE

Time permitting, it is possible to map an area of the skin for pressure. As a stimulus, use a hair stuck to a match stick with paraffin. Apply the hair with uniform pressure, that is, so that the hair just begins to bend. (To measure the force the hair can be applied to a balance.)

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Color Mixing

INTRODUCTION

For the precise, quantitative study of the classic laws of color mixture, the best method is to combine pure spectral lights of known wavelength and intensity. The apparatus required for this method is, however, usually beyond the means of the student laboratory. Fortunately, there exists a good alternative method: the spinning of colored papers on a color wheel or, as it is sometimes called, a "color disk." By means of this simple device, the main laws of color mixture can be easily demonstrated, and approximate quantitative descriptions and predictions can be made.

It has been known since at least the eighteenth century that if two colored patches are presented to the eye in rapid enough succession, the eye is unable to resolve them and sees instead a single resultant color rather than a rapid alternation of two colors. In the nineteenth century, the color wheel as a device for the study of color mixtures was introduced by the physicist James Clerk Maxwell. It consisted of a disk made up of interlaced papers, whose proportions could be adjusted. The disk was spun rapidly on a special top. The modern color disk is like Maxwell's except that it is spun by an electric motor whose speed is adjustable.

One disadvantage of the color wheel, as compared to the direct combining of spectral lights, is that the wavelength composition of the light

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For additional information see pp. 387–396 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

reflected from colored papers is usually not known. Moreover, the light reflected from a given paper usually contains energy from a relatively large portion of the visible spectrum, rather than being confined to a narrow band of wavelengths. Fortunately, however, it has been shown that the results of mixing the colored papers are the same as would be obtained by combining spectral lights having the same appearance as the colored papers—with only one exception. When one spectral light is combined with another, the luminance of the combination equals, to a fairly good approximation, the sum of the luminances of the two components measured separately (the law of additivity). On the other hand, when two colored papers are spun on a color wheel and appear fused, the resulting luminance equals the

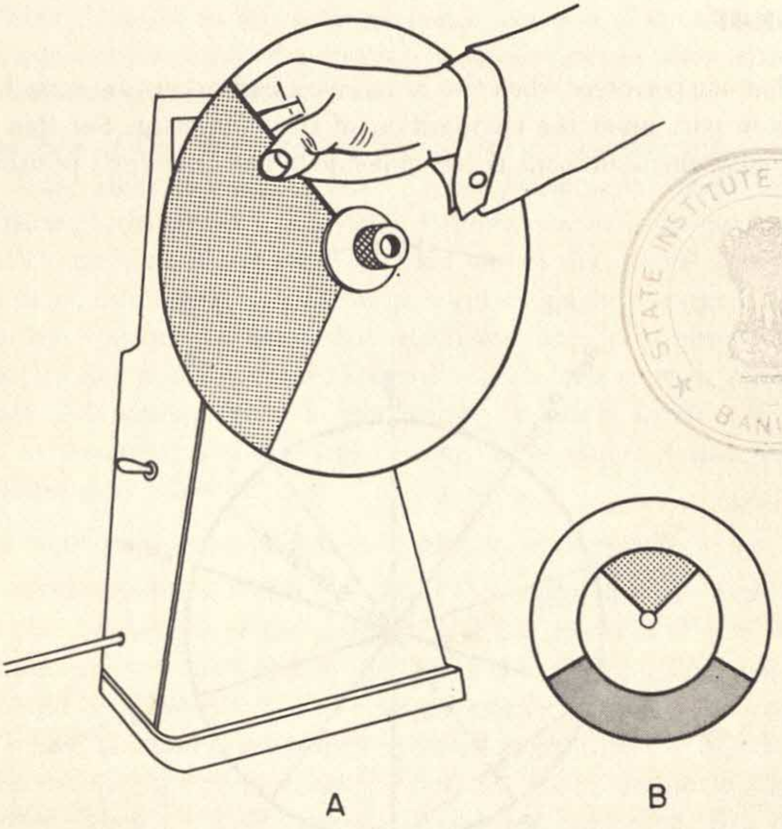

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FIGURE 2-1. Color-mixing apparatus: (A) pair of circular samples mounted on the shaft of the motor. The samples are slotted so as to allow changes in the visible proportions of each; (B) two pairs of samples of different diameters, which will be used in color matching.

average of the luminances of the components taken separately (weighted according to the relative proportions of the two samples).

APPARATUS

A color mixer (Figure 2-1) of adjustable speed; several interlacing colored samples, including a pair of complementary colors; a protractor for measuring the proportions of the color samples exposed to the eye. When colors are to be matched, it is helpful to spin on the same wheel samples having different diameters.

PROCEDURE

What one perceives when two or more colored papers are spun together depends in part upon the composition of the illuminant. For this reason, a good, constant illuminant is recommended. The observer's position with

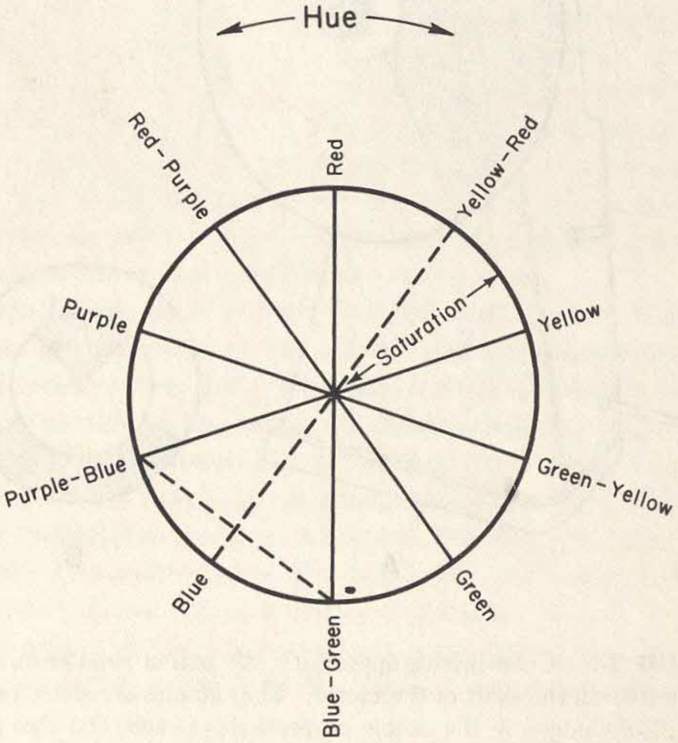

FIGURE 2-2. A simple color diagram.

regard to the color wheel ought to remain the same throughout the experiment, while the experimenter replaces the color samples or adjusts their proportions on the wheel. The wheel is viewed against a neutral gray background in order to avoid the possible effects of color contrast. It is not necessary to run the motors at full speed, but they should run at a speed sufficient to eliminate any residual flicker.

Good color samples are often surprisingly expensive and can easily be soiled and torn. The life of the samples is greatly extended if the students' hands are always clean and if the samples are properly and carefully interlaced on the wheel.

The measurements in this experiment are to be interpreted with the aid of the simple color diagram (Figure 2-2). The color diagram is not to be taken literally in all of its geometric aspects. The student should study the properties of the color diagram in another source before attempting the measurements that follow.

The Rule of Complementaries. Two colors are complementary if, when mixed in the right proportion, they appear achromatic (gray). Any line drawn through the center of the color diagram connects the members of a complementary pair. (The color diagram shows that there exists a host of such pairs, but a good pair of complementary paper samples is not easy to come by. One sure, if somewhat expensive, way is to purchase a pair of Munsell color complements. These will last a long time if treated with great care.) For example, find the relative proportions of a yellow-red sample (4.5 in. in diameter) and a complementary blue sample (same size) that will produce gray under mixture. The equation

$$x \text{ percent yellow-red} + (100 - x) \text{ percent blue} = \text{gray} \qquad (2.1)$$

expresses this condition. With the aid of the protractor, the experimenter adjusts the proportions of the samples, and the observer reports which of the samples appears to dominate the hue of the mixture. The final adjustment should be approached from both directions; that is, if the yellow-red predominates, it should be reduced by small steps until the blue begins to predominate, and the point is noted at which the transition through gray takes place. Then the measurement is repeated beginning with the blue predominant, and the percentage of yellow-red is gradually increased. A methodical procedure of this kind will, in the long run, conserve time and ensure a more reliable measurement.

The Rule of Neighboring Hues. The mixture of any two noncomplementary samples produces a hue that lies intermediate between the hues of the two samples. The hue of the mixture will depend on the relative proportion of the samples. The color of the mixture will be less saturated than the samples, that is, will tend somewhat toward gray—as would be predicted by drawing the appropriate chord on the color circle. For example, place a pair of large (8 in. in diameter) green and purple-blue samples on the color wheel and in front of them, the small blue sample and the gray sample (both 4.5 in. in diameter). The task is to match the blue sample by adjusting the proportions of the green and purple-blue samples. Since the mixture of the latter samples will probably be somewhat lower in saturation than the blue sample alone, it may be necessary to decrease the saturation of the blue sample by mixing it with gray. Obtain the match by a methodical procedure as in the first measurement. This judgment will require more time than the first one because two things must be varied to obtain a good match, the proportions of green and purple-blue and the proportions of blue and gray. It is advisable to concentrate first on getting a match for hue, then to work on saturation, then to refine the match for hue, and finally to refine the match for saturation. (If the gray sample is too dark or too light a little white or black paper can be added to it in order to bring about a perfect match.) The final measurement is expressed in the equation

$$\begin{aligned} y \text{ percent green} + (100 - y) \text{ percent purple-blue} \\ = z \text{ percent blue} + (100 - z) \text{ percent gray} \end{aligned} \tag{2.2}$$

Equivalents. Equations 2.1 and 2.2 can be used to predict other mixtures. The first equation expresses the proportion of yellow-red and blue that results in gray; the second expresses the proportion of purple-blue and green that matches (in hue) blue. We can now write an equation that predicts the proportion of yellow-red, purple-blue, and green that results in gray. Thus, the mixture of purple-blue and green is treated as the equivalent of the blue sample. In formulating the prediction, however, bear in mind that the mixture of green and purple-blue is not as saturated as the blue sample. For example, let us say that z in the second equation turned out to be 50 percent. Then it would take about 10 parts of the green and purple-blue mixture to match about 5 parts of the blue sample and 5 parts of the gray sample. In other words, since the blue produced by mixture is only half as saturated as the blue sample we would need twice as much of the mixture when it is combined on the color wheel with the yellow-red sample. Thus, if 40 parts of the yellow-red and 60 parts of blue were needed to produce gray in Equation 2.1, then we would need 40 parts of yellow-red and 120 parts of the mixture of green and purple-blue in order to produce gray (or in terms of percentages, 25 percent of the yellow-red sample and 75 percent of the mixture of green and purple-blue).

Having determined the values for the third equation, test the predicted values on the color wheel by mixing three small samples. Try to improve on the predicted proportions and compare the settings obtained with those predicted by the equation.

If there is time, experiment with other color mixtures to verify some of the relations shown in Figure 2–2.

Another suggested experiment is to mix, in various proportions, a white sample and a black sample to experience firsthand that the brightness of the mixture lies somewhere between that of the two samples. Also, if a photometer (a device for measuring luminance) is available, one can test the rule that the luminance of a mixture is the weighted average of the luminances of the components, or

$$\frac{x \text{ percent } L_a + (100 - x) \text{ percent } L_b}{2} = L_m \tag{2.3}$$

where L_a is the luminance of one sample, L_b is the luminance of the other sample, and L_m is the luminance of the mixture.

RESULTS AND DISCUSSION

Briefly compare the results of this experiment in relation to the color diagram. Make clear the steps by which Equation 2.3 is inferred. What are some of the limitations of the geometry of the color diagram in portraying the results of mixing? Do your results suggest particular modifications in this geometry?

3

The Reaction Time

INTRODUCTION

The measurement of the reaction time stands among the oldest and most useful measurements in psychology. The simple reaction time is the time that elapses between the onset of a stimulus and the onset of a response. For this experiment a light or a buzzer will serve as the stimulus, and the release of a telegraph key will serve as the response. The main purpose is to compare the average simple reaction time to light with that to sound.

A large number of variables are known to influence the reaction time. Depending on the amount of time you have available, one or two of these variables ought to be investigated. The two suggested here are (1) the effect of stimulus intensity on reaction time and (2) the effect of complicating the reaction by requiring the subject to respond in one way to one stimulus and another way to another stimulus (the disjunctive, as opposed to the simple, reaction).

APPARATUS

A good measurement of reaction time can be achieved with fairly simple equipment.* A satisfactory electrical circuit is shown in Figure 3-1.

For additional information see Chapter 2 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

*In fact, the famous French psychologist Henri Piéron devised a usable method that employs nothing more expensive than a yardstick. The interested reader is referred to Woodworth and Schlosberg, *op. cit.*, pp. 15–16.

Of the components of the apparatus, the chronoscope (a device for measuring elapsed time) is the most critical. One commonly used chronoscope is the Springfield timer, named after the city where it is manufactured, which reads to the nearest $\frac{1}{100}$ sec. The synchronous motor of this timer is driven by 110 volts a-c from the wall outlet; the clutch mechanism that starts and stops the clock hands is operated from a 6-volt d-c power source (a 6-volt battery will do). This source also supplies current for the warning light, stimulus lights, and buzzer. Note that the chronoscope will run and the stimulus will appear only when the subject's key and the experimenter's key are both closed; when the subject's key is released or when the experimenter's switch is turned off, the chronoscope is stopped. The selector switch determines which of the stimuli will occur when the circuit is completed.

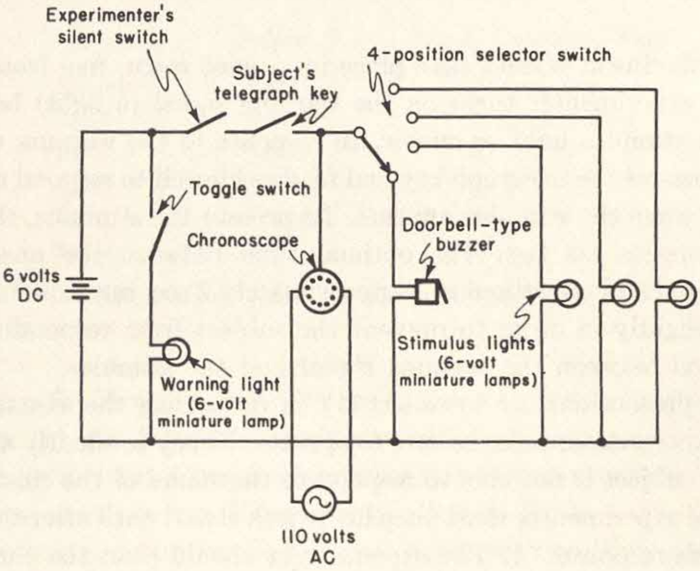
Experimenter's silent switch
Subject's telegraph key
4-position selector switch
Toggle switch
Chronoscope
Doorbell-type buzzer
6 volts DC
Stimulus lights (6-volt miniature lamps)
Warning light (6-volt miniature lamp)
110 volts AC

FIGURE 3-1. Circuit for measuring reaction time.

The stimulus lights and the warning light are mounted on the face of a panel, behind which are located the switches controlling them. The subject's switch is a telegraph key, and the experimenter's switch should have a silent action.

In the measurement of the visual reaction time, the subject must be prevented from responding to the sound produced by the clutch of the chronoscope. Hence the chronoscope should be placed out of earshot; its sounds can be masked by a steady noise heard through earphones.

The intensity of the lights can be reduced by placing film strips of known optical density in front of the stimulus light. For the measurement of the disjunctive reaction time, two telegraph keys are used, only one of which is connected in the circuit at a given time. At the warning signal the subject presses both keys, and the release of the proper key stops the timer.

PROCEDURE

The experiment should take place in a quiet room, free from distractions. The experimenter turns on the warning signal (a light) before presenting the stimulus light or buzzer. In response to the warning signal the subject depresses the telegraph key and readies himself to respond as quickly as possible when the stimulus appears. To present the stimulus, the experimenter depresses his key. The optimal time between the onset of the warning signal and the stimulus is approximately 2 sec, but this time should be varied slightly in order to prevent the subject from responding to the time interval between the warning signal and the stimulus.

A few precautions are in order. (1) In measuring the visual reaction time, the experimenter must be sure to operate the key as silently as possible so that the subject is not able to respond to the sound of the closing of the key. (2) The experimenter must keep his switch closed until after the subject has made his response. (3) The experimenter should reset the chronoscope to zero after recording each measurement. (4) The subject should not be informed of his reaction times until the end of the session.

False Reactions. Sometimes a subject will respond before the stimulus is presented. In itself, such a response is not too serious because it is readily noticed. But it is possible for a response to be initiated just before the onset of the stimulus, yet to occur just after the stimulus has appeared. In this way spuriously short reaction times occasionally are recorded. In order to reduce the number of false reactions, it is conventional to insert "catch trials," that is, the warning light is turned on, but no stimulus follows. If the subject reacts to a catch trial, or at any other time reacts before the onset of the stimulus, the block of trials in which the false reaction occurs is discarded, and the entire block is repeated. The presence of catch trials will tend to discourage false reactions. In this experiment, each block of 16 trials should contain a few additional (2 to 5) catch trials, spaced at random in the block. Decide in advance where these catch trials shall be introduced, and record whether or not false reactions take place.

Practice. The reaction time improves with practice. Fortunately, a large portion of the improvement takes place in the first 20 or so trials. For this reason we start with two practice blocks of 10 trials each.

Problem 1. To determine whether there is a difference in the reaction time to a light and a buzzer, use the Experimental Design Table.

EXPERIMENTAL DESIGN TABLE

Subject 1	*Subject 2*	*No. of Reaction Times*
buzzer	light	10 (practice)
light	buzzer	10 (practice)
buzzer	light	16
light	buzzer	16
light	buzzer	16
buzzer	light	16

(Allow about 1 min rest between the blocks.)

Problem 2. Measure either (1) the reaction time as a function of light intensity or (2) the disjunctive reaction time.

LIGHT INTENSITY. Alternate blocks of trials (high intensity, low intensity, and so on) as in the Experimental Design Table.

DISJUNCTIVE REACTION. The subject depresses two keys, one with the right hand, one with the left. The experimenter presents one of two lights, one located to the subject's left, the other to the right. When the left-hand light appears, the subject reacts by releasing the left-hand key, and vice versa. The stimulus lights are presented in random order. Measure approximately 64 reaction times (32 for each light).

RESULTS AND DISCUSSION

1. Prepare frequency tables (one for visual, one for auditory reaction times, and so on) for the individual subject; that is, record on the tables provided frequency of response for each 1/100 sec interval. A sample frequency table is provided for your use. From the frequency tables construct frequency histograms. (Almost any elementary textbook on statistics can be consulted for suggestions on the preparation

of good histograms.) Choose class intervals so that the nature of the distribution is brought out graphically. How does the general form of the distributions compare with the usual outcome?

2. Compute the mean reaction times. How do these figures compare with each other and with the usual findings? Compute also the geometric means of the reaction times.

$$\text{arithmetic mean} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} \qquad (3.1)$$

$$\text{geometric mean} = \sqrt[n]{x_1 x_2 x_3 \cdots x_n} \qquad (3.2)$$

Or for purposes of computation:

$$\log \text{gm} = \frac{\log x_1 + \log x_2 + \log x_3 + \cdots + \log x_n}{n} \qquad (3.3)$$

How do the arithmetic and geometric means compare? Which mean should have the higher value? What is the advantage of the geometric mean over the arithmetic mean as a measure of location of the "average" reaction time?

3. If you have time, and if you know statistical procedures, the following exercise will be a valuable practical and theoretical lesson. Cumulate the frequency distributions and plot in logarithmic-probability coordinates the percent cumulative frequency (ordinate) as a function of the reaction time (abscissa). For your convenience, sheets of log-probability graph paper are provided in this book. This paper is so constructed that if the logarithm of the reaction time is distributed normally (which is usually approximately true), a straight line will result. Draw the best-fitting straight line through the plotted points. In fitting the line, "weight" the points near the middle of the distribution, for they tend to be more stable than points near the extremes of the distribution. If the distribution is approximately log-normal, you can estimate fairly closely the geometric mean of the distribution (the abscissa at which the line crosses the 50-percent ordinate). The slope of the line is a measure of the variability of the reaction times. The steeper the slope, the less variable are the reaction times. Actually, it is possible to estimate fairly closely the standard deviation of the logarithm of the reaction times. This value is equal to $\log R_{84} - \log R_{50}$, where R_{84} is the abscissa at which the line crosses the 84-percent ordinate, and R_{50} is the abscissa at which the line crosses the 50-percent ordinate. This is true because in a normal distribution,

34-percent of the scores lie between the mean and 1 standard deviation above the mean.

Probability paper offers, therefore, two practical advantages: (1) it permits a graphic conception of the form of a distribution, which depicts whether or not the distribution is normal, and (2) it permits estimation of the mean and standard deviation of the distribution (if normal) without tedious calculations. On the basis of the mean and standard deviation values it is possible to perform a test to decide whether the difference between the means of two distributions should be taken seriously. Since the logarithm of the reaction time, rather than the reaction time itself, is more nearly normally distributed, one actually tests the difference between the means of the logarithms, using the standard deviation of the logarithm of the reaction time, rather than the reaction time as measured. The logarithmic abscissa of log-probability paper will save you the effort of looking up the logarithm of each reaction time measure. (Probability paper that has an arithmetic scale for the abscissa is also available.)

4. What conclusions may be drawn from the differences produced in reaction times by the intensity of the stimuli? How does the question of intensity relate to differences in the reaction times from one sense modality to another?

Why should disjunctive reaction times be longer than simple reaction times? Consider various alternative explanations.

5. Discuss the possible sources that contribute to the rather high variability of the simple reaction time.

Frequency Table for the Measurement of Reaction Time

EXPERIMENTER____________________

SUBJECT____________________

	Stimulus 1________			**Stimulus 2**________		
Reaction Time in 1/100 sec	*Frequency*	*Cumulated Frequency*	*Percent Cumulated Frequency*	*Frequency*	*Cumulated Frequency*	*Percent Cumulated Frequency*
—						
—						
—						
—						
—						
—						
—						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						

	Stimulus 1			**Stimulus 2**		
Reaction Time in 1/100 sec	*Frequency*	*Cumulated Frequency*	*Percent Cumulated Frequency*	*Frequency*	*Cumulated Frequency*	*Percent Cumulated Frequency*
24						
25						
26						
27						
28						
29						
30						
31						
32						
33						
34						
35						
36						
37						
38						
39						
40						
—						
—						
—						

4

Differential Sensitivity to Weight

INTRODUCTION

The capacity for discriminating small differences in stimulus level can be expressed by means of the Weber fraction, $\Delta I/I$, named in honor of the nineteenth century physiologist Ernst Weber. In this quotient, I stands for a given level of the stimulus and ΔI for an increment that when added to I produces a just-noticeable difference in sensation (sometimes called the "difference limen"). By "just-noticeable difference," we mean a change in stimulation that is perceptible with a certain likelihood—say 50 percent or 75 percent of the time. Thus, the Weber fraction represents a statistical measurement of the variability (or limit of sensitivity, depending on the point of view) of the sensory process.

In the nineteenth century, several methods were invented and refined for the measurement of this variability. The originator of this field of inquiry, usually called "psychophysics," was the German physicist-philosopher Gustav Fechner, to whom we owe the three classic psychophysical methods: constant stimuli, limits, and average error. In this experiment we will use the method of constant stimuli to measure the Weber fraction for lifted weights.

Although the enterprise of measuring difference limens has continued to occupy the attention of many psychologists, sometimes perhaps to the exclusion of what William James once called the "more nutritious objects of attention," the science of psychophysics has in recent years enlarged its

For additional information see Chapter 8 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

scope to include a greater variety of interesting sensory problems and new methods for investigating them. But despite the "new look" in psychophysics, the use of the classical methods for the measurement of the Weber fraction on several sensory continua has led to a famous and important generalization, *Weber's law.* This law states that the Weber fraction for a given sensory continuum is a constant, or, in other words, that the just-noticeable difference ΔI is a constant proportion of the stimulus level I, to which it is added, or again

$$\frac{\Delta I}{I} = k \qquad \text{or} \qquad \Delta I = kI \tag{4.1}$$

The constant k differs from one continuum to another and may be regarded as an index of the precision of the judgments of sensory differences in a particular continuum. When k is low, precision is high; when k is high, precision is low. Or, to put the whole matter in quite different language, the error in sensory judgment tends to be of the constant-percentage type (a common state of affairs in the world of physical measurement); the percentage error can vary greatly from one sensory system to another and, to a lesser degree, from one individual to another.

Actually, Equation 4.1 does not square with the empirical findings for stimuli near the absolute threshold. A revision of Weber's law that can sometimes handle empirical findings throughout the sensory continuum is

$$\Delta I = k(I + C) \tag{4.2}$$

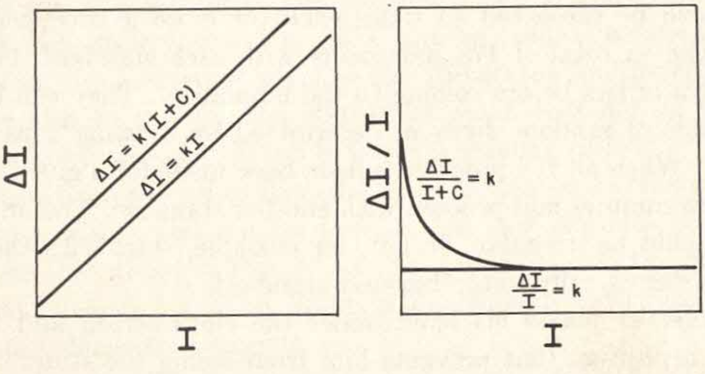

FIGURE 4-1. The linear generalization of Weber's law. Each of the two panels shows the predictions of Equations 4.1 and 4.2. The left panel shows how the just-noticeable difference (ΔI) would vary with intensity for the two equations; the right panel shows how relative error ($\Delta I/I$) would vary with intensity for the two equations.

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This equation is the *linear generalization of Weber's law* (see Figure 4-1). Note that the equation is linear and that as the value of I increases, the constant C influences less and less the value of the Weber fraction. In our experiment, we will measure the Weber fraction at four different values of I and see how well the findings agree with Equation 4.2.

APPARATUS

Use as stimuli four standard weights and four sets of comparison weights, as suggested in the accompanying table. All the weights have the same volume.

A satisfactory set of weights can be economically prepared by pouring the right amount of a mixture of melted paraffin and lead shot into small plastic bottles (roughly 1.5 in. in diameter and 1.5 in. high). A cloth screen is used to prevent the observer from seeing the weights.

Each student will bring a subject (observer) to the laboratory.

PROCEDURE

In the method of constant stimuli, the observer lifts first the standard and then one of the comparison weights. He then reports whether the comparison feels heavier or lighter than the standard. Some experiments allow the observer to use a third category of response ("equal weight"), but in this experiment the third category will be ruled out. The 5 comparison stimuli should be presented 35 times each (or more if time permits), in random order—a total of 175 judgments with each standard. (Work out these random orders before coming to the laboratory. They can be copied out of a table of random digits or determined by drawing slips of paper from a hat.) When all 175 judgments have been made for a given standard, rest for a few minutes and proceed with another standard. The order of the standard should be irregular; do not, for example, start with the lightest and work systematically to the heaviest standard.

The observer places his hand under the cloth screen and sits comfortably in a position that prevents him from seeing the stimuli. The experimenter puts the weights in the same place from trial to trial so that the observer can find them easily. The experimenter should avoid giving any clues about the stimuli being judged. For example, if the same weight is presented twice in a row, it should be removed after the first judgment, placed with the other weights, and then returned to the observer.

SUGGESTED STIMULI FOR THE EXPERIMENT

Standard Stimulus (grams)	*Comparison Stimuli (grams)*				
50	45	47.5	50	52.5	55
100	90	95	100	105	110
200	180	190	200	210	220
400	360	380	400	420	440

ANALYSIS OF THE RESULTS

For each standard, make the following analysis. Tabulate for each comparison stimulus the number of "heavier" judgments. (The number of "lighter" judgments equals, of course, 35 minus the number of "heavier" judgments, but since errors of tabulation are exceedingly common, it is usually worth the extra effort to tabulate the "lighter" judgments separately as a check on accuracy.) A graph (known as the "poikilitic function") showing the percentage of "heavier" responses as a function of weight typically yields an approximation to a normal ogive (the so-called phi-gamma hypothesis). Plot the results (1) in arithmetic coordinates and (2) on probability paper. Sheets of probability paper are included in this manual for this purpose. On the first graph sketch the rough form of the normal ogive. On the second graph fit a straight line (again in accordance with the phi-gamma hypothesis) to the points, giving more consideration to the middle three points than to the two end points. (Why?) Determine the abscissas at which the line intersects the 25-percent, 50-percent, and 75-percent ordinates. The difference limen (ΔI) will be defined as the distance (in grams) from the 50-percent point to the 75-percent (or 25-percent) point.

Note that in general, the 50-percent point does not lie at the value of the standard stimulus. What is this discrepancy called?

Results from the entire class should be tabulated and distributed. Find the average Weber fraction for each of the four stimulus series. Prepare the graphs (like those in Figure 4-1) to show how well the measurements agree with Weber's law. Test Weber's law for your individual results, too, if they are sufficiently clear-cut.

DISCUSSION QUESTIONS

1. Before evaluating the results of this experiment, the student is advised to reflect on the general nature of experimental error. For

example, what different kinds of error are encountered in an experiment of this kind?

2. If in the probability graph the points do not lie exactly on the straight line, does this necessarily invalidate the phi-gamma hypothesis?

3. What interpretation can be made of the phi-gamma hypothesis? Are there plausible alternative hypotheses?

4. How can one account for the great interest in measuring the difference limen?

5. What advantages or disadvantages attach to the use of a third response category in the method of constant stimuli?

6. How would the form of the poikilitic function be expected to change if correct responses are rewarded and incorrect responses are punished? What does your answer imply concerning the generality of the phi-gamma hypothesis?

7. What is the method of "single stimuli"? How do results obtained with this method typically compare with the constant method? How do results obtained with the method of limits compare with the constant method?

5

An Introduction to Psychophysical Scaling

One of the most prominent features of sensory experience is that sensations vary in magnitude—from dim to bright, from soft to loud, from heavy to light, and so on. To the founder of psychophysics, Gustav Fechner, a primary goal of this science was to discover the exact way in which the magnitudes of our sensations are related to the physical stimuli that arouse them. For at least some continua it becomes fairly obvious that the magnitude of the sensation is not a simple linear function of the physical intensity. For example, if the physical intensity of a light source is doubled, the increase of the apparent brightness, though perceptible, is surprisingly small—nothing like "twice as bright."

On the basis of Weber's law and on the questionable assumption that all just-noticeable differences in magnitude are subjectively equal, Fechner formulated his famous generalization that the subjective magnitude grows as the logarithm of the physical intensity; or to state it another way, equal differences in subjective magnitude correspond to equal ratios of physical magnitude. Despite some objections to the underlying assumptions and despite the occasional proposals of alternative functions, of which perhaps the most notable was provided by the Belgian physicist Plateau, Fechner's

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For additional information see pp. 141–154 in Galanter, E., Contemporary psychophysics, *New Directions in Psychology* (New York: Holt, Rinehart and Winston, 1962). Also see Stevens, S. S., The surprising simplicity of sensory metrics. *American Psychologist* (1962), *17*, 29–39; Stevens, S. S., Problems and methods of psychophysics. *Psychological Bulletin* (1958), *54*, 177–196; and Stevens, S. S., On the psychophysical law. *Psychological Review* (1957), *64*, 153–181.

law gained acceptance among the scientists of the nineteenth and twentieth centuries.

The construction of the logarithmic law is nevertheless widely conceded to be a rather indirect and questionable process, in that one goes from the measurement of the variability (or precision) of sensory judgments to statements about sensory magnitudes. Direct ways to test its validity were already conceived in the nineteenth century, but for a number of reasons the early experiments failed to decide the issue. Recent decades, principally because of the work of S. S. Stevens, have seen the development of a variety of direct methods, of which a few are illustrated in these laboratory exercises. The methods have in common that they call upon the observer to make some kind of direct assessment of the magnitude of sensation, such as the assignment of numbers in proportion to the subjective magnitudes of a set of stimuli on the continuum. For most sensory continua the results appear to contradict the logarithmic relation proposed by Fechner, and instead they strongly support the virtually forgotten proposal of Plateau that the sensation might grow as a power function of the physical magnitude, or stated in other words, that equal ratios of sensory magnitude correspond to equal ratios of physical magnitude. If ψ is the subjective magnitude and φ is the physical intensity, and k is some constant of proportionality, then Fechner's law states that

$$\psi = k \log \varphi \tag{5.1}$$

or, for any two values of φ, that

$$\psi_1 - \psi_2 = k \log \left(\frac{\varphi_1}{\varphi_2}\right) \tag{5.2}$$

but the power law states that

$$\psi = k\varphi^n \tag{5.3}$$

or, for any two values of φ that

$$\frac{\psi_1}{\psi_2} = \left(\frac{\varphi_1}{\varphi_2}\right)^n \tag{5.4}$$

By the direct methods, the power law has been found to hold true, at least approximately, for more than two dozen sensory continua, including subjective loudness, brightness, heaviness, warmth, cold, length, taste, and duration, to mention a few. Each of these continua has its own characteristic exponent n. (How the shape of the psychophysical function relates to the size of the exponent is shown in Figure 5-1.) For example, the exponent governing the equation for the brightness of a spot of light viewed by the dark-adapted eye is 0.33, the exponent for electrical current passed through the fingers is about 3.5, and the exponent for the length of a line is about 1.

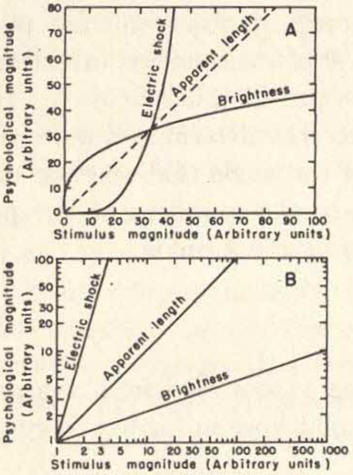

FIGURE 5-1.

An exponent greater than 1 means that the sensation grows more rapidly than the stimulus; an exponent smaller than 1 means that the sensation grows more slowly than the stimulus (see Figure 5-1). For a given sensory modality the exponent can sometimes be altered. For example, its value for brightness is larger for the light-adapted eye than for the dark-adapted eye.

In Figure 5-1 the power functions for brightness, length, and electric shock are plotted in linear coordinates (A) and in logarithmic coordinates (B). In log-log coordinates the power functions all become straight lines. This is because the equation for the power function can be rewritten (taking the logarithm of both sides of Equation 5.3) as

$$\log \psi = n \log \phi + \log k \tag{5.5}$$

The exponent n which relates in Figure 5-1A to the *shape* of the function becomes the *slope* of the straight lines in 5-1B. The proportionality constant k is usually of little interest because its value is determined by the arbitrary choice of units of measurement. For example, in the scaling of apparent length its value will depend on whether we measure the stimulus in inches, centimeters, meters, and so on. The size of the exponent, and therefore the *shape* of the psychophysical function, does not depend on the choice of the unit.

HOW TO TEST FOR A POWER FUNCTION

Equation 5.5 and Figure 5-1B illustrate a simple means of testing whether a set of data can be described by a power function. The data (say the averaged numerical estimates of a group of observers) are plotted (ordinate) as a function of the physical level of the stimulus (abscissa) on log-log paper. (Samples of log-log paper are provided in this book.) If the plotted points fall along a straight line, then they determine a power function. The slope of this line (the tangent of the angle that the line makes with the horizontal) is numerically equal to the exponent of the power function. The value of k can then be gotten by the formula

$$k = \frac{\psi_1}{\phi_1{}^n} \tag{5.6}$$

where ψ_1 and ϕ_1 are any two corresponding values read from the graph. (A suggested exercise is to draw a few straight lines in log-log coordinates and determine their equations.)

DIRECT PSYCHOPHYSICAL PROCEDURES

Many different techniques have been used to scale subjective magnitude, and a complete catalogue of their variety, together with their relative advantages, goes beyond the scope of this discussion. Instead, we will explore three of the most commonly used and generally satisfactory methods.

Magnitude Estimation. In this method, the observer assigns numbers to various levels of the stimulus in proportion to their subjective magnitude. Since the variability of the numerical estimates is fairly large, it is necessary to average the results of a group of subjects (say 10 or 12) in order to get a stable and representative function.

There are, of course, a host of conceivable ways to carry out this simple experiment. Many of these ways have been tried, and the effects of variations in procedure are available in the literature for those who have the curiosity and industry to seek them out. By way of summary, however, the following "rules," among others, seem to emerge from the methodological research:

1. The number of judgments in a given session should not be too large. A relatively small number of judgments from a group of

alert subjects is preferable to a large number from a bored and inattentive subject. The usual procedure is to let the subject make a couple of judgments for each of seven or eight stimuli spaced out sensibly over a fairly large portion of the continuum.

2. The order in which the stimuli are presented should be irregular and different from one observer to another. For example, it is unwise to start with the lowest level and proceed in order to the highest. The level of the first stimulus presented should probably be chosen from somewhere near the middle of the range, rather than from the extremes.

3. The observer is instructed to choose a convenient and reasonable number to stand for the subjective magnitude of the first stimulus, and thereafter to assign numbers in proportion to the subjective magnitude of the other stimuli. The word "proportional" can be explained: for example, a sensory magnitude that seems three times as great as that of the first stimulus should receive a number three times as large; one that seems $1/10$ as large should receive a number $1/10$ as large. The scale is "unbounded" in the sense that decimals can be assigned to very small magnitudes and likewise there is no upper limit to the numbers available for very large magnitudes.

A variation of this procedure is to assign a convenient modulus, say the number 10 or 20 to the first stimulus, but in general it is probably better to let the observer choose the number he considers to be the most convenient and sensible.

4. It is not necessary, or even particularly advisable, to consider the first stimulus as a "standard" that is presented prior to each of the other stimuli. Although the observers may feel more comfortable having a standard, this procedure lengthens the session unnecessarily and fails to produce a superior set of judgments.

5. The comfort and the convenience of the observer should always be a primary concern. For example, it is good to let the observer control the onset of a stimulus by pressing a switch, so as to be prepared for its occurrence.

6. The arithmetic mean is not a very good measure of central tendency because the distribution of the judgments of a number of observers is usually skewed. The median, although it circumvents the problem of skewness, is relatively unstable unless the number of judgments is large. It has been found that to a rough approximation the distribution of the judgments for a particular stimulus is normalized

by a logarithmic transformation; this implies that the geometric mean is a suitable average (see Chapter 3).

Magnitude Production. This method is essentially the inverse of magnitude estimation, in that the observer adjusts the level of the stimulus so that the resulting sensory magnitudes are proportional to a set of numbers called out by the experimenter. The logic of the rules for magnitude estimation should be applied also to this procedure. Provision must be made, of course, to vary the stimulus level continuously over a very wide range. If the available range is too small, the observer's settings will obviously be biased.

Magnitude production serves as a suitable complement to magnitude estimation, for as a general rule the combined results of two inverse procedures are likely to yield a more valid outcome than a single, potentially biased, procedure.

Cross-modality Matching. This method circumvents the use of numbers. Instead, the observer adjusts one stimulus, say a light, so that it appears to match the intensity of another stimulus, say a noise (or vice versa). What at first glance may perhaps seem a rather unlikely procedure has proved itself valuable as a means of checking on the validity of the psychophysical functions measured by numerical assessment.

Given two sensory continua a and b governed by the power functions (setting the arbitrary proportionality constants equal to 1 in both cases)

$$\psi_a = \phi_a^n \tag{5.7}$$

and

$$\psi_b = \phi_b^m \tag{5.8}$$

then, if the observer's task is to equate ψ_a and ψ_b at various levels, we predict that the matches will generate an equal-sensation function of the form

$$\phi_a^n = \phi_b^m \quad \text{or} \quad \phi_a = \phi_b^{m/n} \tag{5.9}$$

Note that Equation 5.9 is itself a power function governed by the exponent m/n; if the results of cross-modality matching can be fitted by Equation 5.9, they constitute good evidence that the functions a and b obtained by numerical assessment are valid. Such has been the outcome of a number of attempts to use the method.

The three methods described here are applied in the two subsequent chapters to several sensory continua. It is suggested that, depending on the available time and equipment, a representative selection of continua and methods be explored in one or two laboratory sessions. Students may use each other as subjects or may bring naïve subjects to the laboratory, but it is advisable for the student at any one time to serve both as experimenter and as subject. In any case, precautions should be taken not to let the subjects be biased by each other's judgments. For example, in the experiments using magnitude estimation, the estimates can be written down on slips of paper, rather than called out to the experimenter, who may later serve as a subject in the same experiment.

To get a "feel" for the direct scaling methods the following short but useful class exercise is suggested. One of the students is appointed to prepare a set of six or seven sticks ranging in length from about 1 to 30 in. These are displayed to the class briefly, one by one, in irregular order until each has been shown two or three times. Each person writes down numbers proportional to the apparent length. The medians of the estimates can be plotted in log-log coordinates, a line fitted to the points, and the equation of the line computed. The experience of estimating length can be quite helpful as an exercise preliminary to the judgment of more difficult continua.

6

The Method of Magnitude Estimation

The problem is to use the method of magnitude estimation to determine the psychophysical function for one or more of the following continua: (1) tactual roughness, (2) brightness of a white light, and (3) loudness of a noise. The student should read Chapter 5 before any of these experiments is attempted. It is also suggested that, time permitting, the same continua be scaled by the method of category-rating, a procedure introduced toward the end of this chapter.

ROUGHNESS

The stimuli are emery cloths of different roughnesses, which the subject feels by drawing his finger across the paper. The measure of the stimulus is the reciprocal of the grit number of the emery cloth. (The grit number is the reciprocal of the average diameter of the particles of the abrasive; hence our measure of the stimulus is proportional to the particle size of the cloth.) Stevens and Harris* found that the sensation of roughness grows as about the 1.5 power of this measure.

Eight or ten emery cloths, chosen by the instructor and ranging from

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For additional information see Stevens, S. S., The surprising simplicity of sensory metrics. *American Psychologist* (1962), *17*, 29–39; Stevens, S. S., Problems and methods of psychophysics. *Psychological Bulletin* (1958), *55*, 177–196; and Stevens, S. S., On the psychophysical law. *Psychological Review* (1957), *64*, 153–181.

*Stevens, S. S., and J. R. Harris, The scaling of subjective roughness and smoothness. *Journal of Experimental Psychology* (1962), *64*, 489–494.

about grit numbers 320 to 24, serve as the stimuli. The subject is prevented from looking at the cloths or knowing their values. Each stimulus is presented and estimated three times in the course of the experimental session.

The geometric mean of the estimates of a group of subjects is plotted (ordinate) in log-log coordinates (samples of log-log paper are provided) as a function of the reciprocal of the grit number (abscissa). Draw a line that best fits the points, determine its equation, and compare the result with that of Stevens and Harris.

BRIGHTNESS

The experiment should be conducted in a darkened room or the observer should use an eyepiece constructed to shield himself from extraneous light. The stimulus is a white luminous spot subtending about 4 deg of visual arc and viewed from a distance of about 15 in.

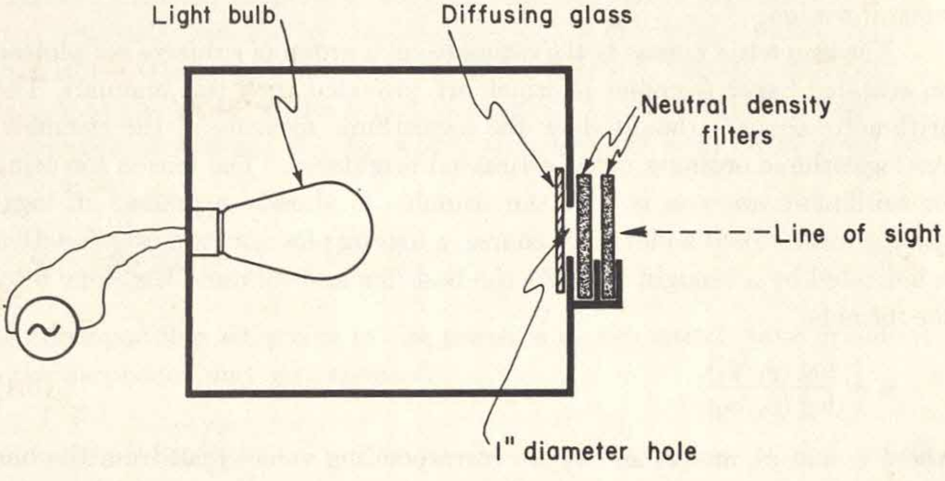

FIGURE 6-1. Side view of light apparatus for brightness scaling.

The apparatus (see Figure 6-1) can be a bright light mounted in a box having on one side a hole about 1 in. in diameter. Over this hole is mounted a sheet of diffusing glass, such as flashed opal glass or Plexiglas, to give the stimulus spot a uniform brightness. The intensity of the spot is varied by means of one or more neutral density filters placed in front of the luminous spot. These filters are calibrated by the manufacturer in terms of *log density*, that is, a filter designated "1" transmits $1/10$ of the incident light; a filter designated "2" transmits $1/100$ of the light, and so on, since density is the reciprocal of transmittance. The two filters placed tandem (as shown in Figure 6-1) would have a combined density of 3 log units, that is, would transmit $1/1000$ of the incident light.

The absolute luminance of the spot can be measured with a photometer, but to obtain the exponent of the brightness function it is not really necessary to know the absolute values, merely relative ones; and, of course, the relative amounts of transmitted light can be directly determined from the density values of the calibrated filters.

If the light source is fairly intense (about 1 lambert or more) it should be possible to scale a range of 5 or 6 log units (50 or 60 db). Thus, use six or seven stimuli spaced 1 log unit apart.

The subject first dark-adapts for 10 min. Then each stimulus level is presented for about 1 sec each, allowing about 10 sec between successive exposures for the changing of filters and for the recovery of the eye's sensitivity. Each stimulus is presented twice in the course of the experimental session.

The geometric means of the estimates of a group of subjects are plotted on semi-log paper (samples of which are provided with this manual). The arithmetic abscissa should show the logarithmic measure of the stimulus; the logarithmic ordinate is the estimated brightness. (The reason for using an arithmetic abscissa is that the stimulus is already expressed in logarithmic form.) Such a plot is, of course, a log-log plot, and a power function is indicated by a straight line. Fit the best line and compute the slope n by the formula

$$n = \frac{\log (\psi_1/\psi_2)}{\log (\phi_1/\phi_2)} \tag{6.1}$$

where ψ_1 and ϕ_1, and ψ_2 and ϕ_2 are corresponding values read from the line on the graph. If we choose ϕ_1 and ϕ_2 so that they are separated by 1 log unit, then the formula becomes simply

$$n = \log \left(\frac{\psi_1}{\psi_2}\right) \tag{6.2}$$

The results of many experiments on brightness indicate that the brightness grows approximately as the cube root ($1/3$ power) of the luminance level. How well does the present outcome agree with this?

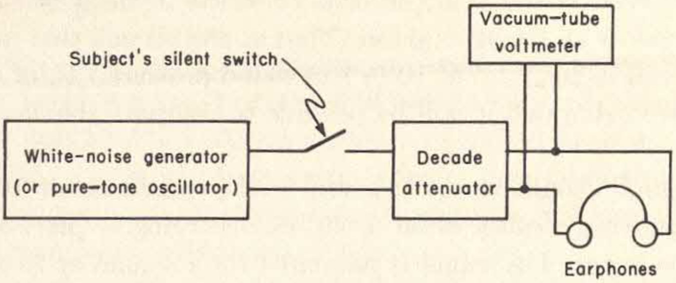

FIGURE 6-2. Block diagram of apparatus for the scaling of loudness.

LOUDNESS

The stimulus is a white noise (or a tone, but preferably a noise), heard through a pair of good earphones, whose intensity is controlled by means of a decade attenuator (see Figure 6-2). A vacuum-tube voltmeter, wired in parallel with the earphones, may be used to ensure that the electrical signal is actually reduced by the amounts indicated by the numbers on the attenuator. Attenuators are calibrated in decibels, which constitute a measure of the ratio of the input voltage V_i to the output voltage V_o; the number of decibels N_{db} by which the signal is reduced is given by the formula

$$N_{db} = 20 \log \left(\frac{V_i}{V_o}\right) \tag{6.3}$$

The corresponding reduction in the pressure of the sound wave produced by the earphones may be expressed

$$N_{db} = 20 \log \left(\frac{P_1}{P_2}\right) \tag{6.4}$$

where P_1 is the pressure produced by V_i (unattenuated signal) and P_2 is the pressure produced by V_o (attenuated signal).

A relative measure of the sound pressure can be gotten either from reading a voltmeter or by relying on the attenuation values. Good attenuators are usually reliable (although they should be checked), especially if the signal from the generator is never attenuated by less than 10 db.

To measure the exponent of the loudness function, only the *relative* intensity levels of the sound are needed. These can be easily calculated from the decibel values on the attenuator. (That is, two stimuli that are different by 20 db stand in the ratio of 10 to 1 in sound pressure.) If, of course, the earphones are calibrated it will be possible to compute the *absolute* sound pressure.

The stimuli should be six or seven levels, spaced about 10 db apart, and thus spanning a range of 50 or 60 db, according to precise directions from the instructor. The sound is presented for a second or two at a time, and each level is presented twice in the course of the experiment.

The geometric means of the estimates of a group of subjects should be plotted on the semi-log paper. The ordinate should show the subjective (estimated) loudness. The stimulus intensity can be expressed as attenuation in decibels, but the values should be plotted from left (high attenuation, low sound pressure) to right (low attenuation, high sound pressure). The plot is effectively a log-log plot because the computation of the decibel values involves a logarithmic transformation. Draw the straight line that best fits the points. Since a pressure ratio of 10 to 1 is a 20 db difference you can compute the slope by the formula

$$n = \log \left(\frac{\psi_1}{\psi_2} \right) \tag{6.5}$$

where ψ_1 and ψ_2 are the ordinates corresponding to any two abscissa values separated by 20 db.

The results of many experiments indicate that subjective loudness grows approximately as the 0.6 power of the sound pressure. How closely do the present results agree with this finding?

RESULTS AND DISCUSSION

The graphs should be discussed in terms of the alternative psychophysical laws, the previous experimental work on the continuum, and the particular sources of error encountered in the experiment.

It has been said that a large potential source of error in psychophysical experiments is the observer's "conservatism," that is, his tendency to foreshorten the range of the variable he is manipulating (in the present experiments, the number continuum). Would this bias tend to make the slope of the psychophysical function too steep or too flat? How would the same bias be expected to influence the results of magnitude production?

CATEGORY SCALING

A scaling procedure not discussed in Chapter 5, but one put to extensive use in psychology is the method of category rating. The basic idea is that the subject tries to partition a portion of a continuum by placing a set of stimuli into a number of categories, usually 5 or 10 of them. Often the categories are conveniently designated by numbers, for example, the numbers 1 through 5 for a 5-category scale.

In principle, what the subject does under these instructions should be predictable from the scale obtained by magnitude estimation or one of the other ratio-scaling procedures; in fact, however, this is not usually true. We expect the average category number assigned to be a linear function of the average magnitude estimate; instead, the function usually has a concave (downward) shape.

Just why the category scale is usually not a linear function of the subjective magnitude is a subject of considerable experiment, speculation, and debate, but the answer does not seem to be easily come by. For one thing, the exact shape of the category scale is so easily influenced by the way in which the stimuli are "spaced." It is also not clear just what the subject attempts to do under the instructions to categorize.

A very simple and brief experiment will help to make clear the nature of the category problem. The stimuli from one of the three experiments above are presented one by one to the subject, who assigns them to one of seven categories designated by the whole numbers from 1 to 7. (The exact number of categories is not very important, except that everyone should use the same number.) Before the judging starts, the subject is given the lowest stimulus (which he is told belongs to the first category) and the highest stimulus (which he is told belongs to the seventh category). The stimuli are then presented in irregular order, each stimulus being presented three times in all.

The category numbers are averaged and plotted on ordinary arithmetic graph paper. The average category number is plotted on the ordinate as a function of the geometric mean of the magnitude estimates of the same stimulus (abscissa). (For the purpose of this experiment, one may use either the arithmetic or the geometric mean of the category assignments.) Sketch in a smooth curve to show the trend of the data. Was the usual category effect obtained? Interpret in the light of what is known in general concerning the relation between scales of subjective magnitude and scales obtained by partitioning a continuum.

7

Magnitude Production and Cross-modality Matching

In the first part of this exercise a scale of apparent length is obtained using the method of magnitude production. This scale can be used, together with the results obtained by the method of magnitude estimation (see Chapter 6) to predict what will happen in the second part of the exercise, which is the cross-modality matching of length to another continuum. These psychophysical methods and the procedure by which the matches are predicted are discussed in Chapter 5.

MAGNITUDE PRODUCTION OF APPARENT LENGTH

The apparatus can be a 2-meter stick suspended horizontally in front of the subject by means of a ringstand and clamp at either end (Figure 7-1). The side of the meter stick facing the subject should be a plain, unmarked surface, except for a single straight black line running the length of the stick. Hanging on the stick are two movable pointers which the subject, using both hands, adjusts to mark a segment of the black line. The experimenter reads the length of the adjusted segment from the other, marked surface of the stick. (The same apparatus can, of course, be used for magnitude estimation, with the experimenter adjusting the line segment. Time per-

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For additional information see Stevens, S. S., The surprising simplicity of sensory metrics. *American Psychologist* (1962), *17*, 29–39; Stevens, S. S., Problems and methods of psychophysics. *Psychological Bulletin* (1958), *55*, 177–196; and Stevens, S. S., On the psychophysical law. *Psychological Review* (1957), *64*, 153–181.

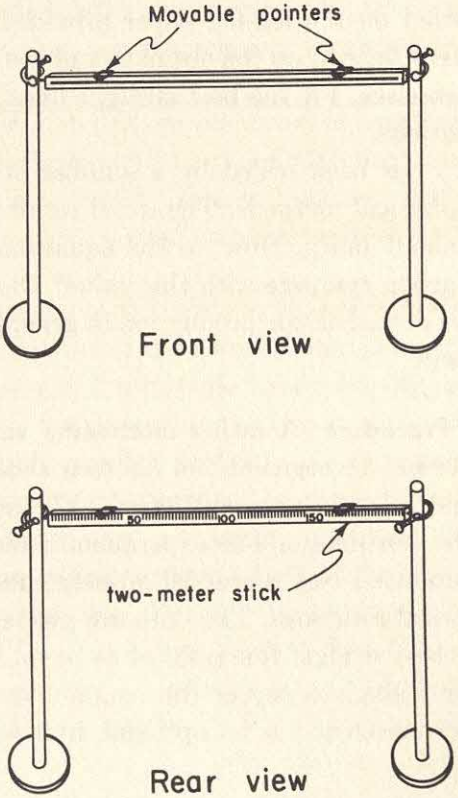

FIGURE 7-1. Apparatus for the judgment of apparent length.

mitting, such an experiment can be profitably undertaken in order to compare the results from the two psychophysical procedures.)

The subject is instructed to form line segments whose apparent lengths are proportional to the numbers called out, in irregular order of magnitude, by the experimenter. The following numbers are suggested: 1, 2, 5, 10, 20, 30, and 40. It is unwise to attempt a very large portion of the continuum, lest the observer be biased by the limited range offered by the stick; and if the observer feels unable to set a large or small enough magnitude, a judgment should not be demanded from him at that value.

Each number is called out three times in the course of the session. Between settings the experimenter puts the markers at a random distance apart. The subject should "zero in" on the final setting—that is, alternately produce values that appear too large and too small to be correct. The geometric means of the settings of the individual subject and of a group of subjects can be plotted on the log-log paper provided. Plot the numbers called for (the apparent length) on the ordinate and the lengths adjusted by the subject on the abscissa. Fit the best straight lines to these points and determine their equations.

Apparent length has been scaled by a number of investigators using a variety of psychophysical methods. The usual result is a power function whose exponent is about unity. How do the equations for the individual subject and for the group compare with this value? Discuss the biases that attach to the method of magnitude production in general and to its application in this experiment.

An Alternative Procedure. A rather interesting variation is to let the subject set a number of line segments, of his own choosing, and to assign numbers proportional to their apparent length. The subject tries to scale a wide portion of the continuum. The experimenter records the lengths of the line segments produced (say about 20 adjustments) and the subject's corresponding numerical estimates. The data are plotted directly in log-log coordinates, and the best straight line is fitted to them. Because the method yields a function for a single observer (no simple averaging is, of course, possible) its use is recommended as an optional, individual exercise in psychophysical scaling.

CROSS-MODALITY MATCHING

In the method of magnitude estimation the subject is called upon to match a portion of the number continuum to a portion of a sensory continuum; in this experiment the task is to match a portion of one sensory continuum to a portion of another sensory continuum.

The continua will be (1) apparent length, which the subject adjusts and (2) one of the continua studied in Chapter 6—roughness, brightness, or loudness. The stimuli to be matched can be the same set used for magnitude estimation. (In an ideal, balanced experiment, the continuum to be matched should also be used as the criterion continuum; for example, the brightness of a light should be adjusted to match the apparent length of a set of line segments as well as the other way around.)

If brightness is the continuum to be matched, a problem arises how both to maintain dark adaptation and have the observer see the 2-meter stick on which the matching line segment is set up. One simple solution is to illuminate the stick with a relatively dim red light; another is to use a binocular eyepiece that permits one eye to view the light stimulus and the other to view the line segments.

The stimuli to be matched are presented in irregular order with respect to magnitude until each stimulus has been matched twice. As in magnitude production, the subject should "zero in" on the final setting and should report his inability to make a good match if he feels restricted by the length of the stick.

The geometric means of the settings of a group of subjects are plotted on the ordinate as a function of the stimulus that is matched. If the matched continuum is roughness it is advisable to use log-log paper; for brightness and loudness use semi-log paper for the reason given in Chapter 6.

The student should predict explicitly the outcome of the experiment and compare the actual outcome with the prediction.

In the report, state what advantage might be gained by doing the reverse experiment, in which segments are matched by adjusting the magnitude of the other stimulus. Discuss the psychological nature of cross-modality matching. To what extent, if any, does the validity of the cross-modality procedure depend on obtaining an "absolute" match between quantities on two different continua? For example, under what conditions might it be possible for two observers who set quite different absolute lengths nevertheless to be in essential agreement in their judgments?

8

Discrimination of Depth

INTRODUCTION

The study of depth perception has a long history among students of natural philosophy and of the visual arts. Painters came gradually to recognize and use cues to depth such as shadows and perspective. In the early eighteenth century the English philosopher Berkeley noted that depth perception might be mediated by muscle sensations evoked by the convergence of the two eyes. In the nineteenth century another type of "binocular" cue was added by the physicist Wheatstone: the disparity between the images in the two eyes.

Along with the proper recognition of the role of binocular factors came a number of attempts to measure the precision of depth discrimination, and it was soon discovered that the sensitivity of the visual system is remarkably keen, especially when binocular cues are permitted. Helmholtz, for example, reported an experiment in which he viewed three pins in a plane perpendicular to the visual axis, and measured the displacement of one of the pins necessary for detecting that it fell out of the plane.* He concluded that the "comparison between the images on the retina of the eyes can be made with the same degree of accuracy as that of the perception of the smallest

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For additional information see pp. 455–480 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

*von Helmholtz, H. *Helmholtz's treatise on physiological optics* (Ed. and trans. by J. P. C. Southall) (Rochester, N.Y.: Optical Society of America, 1924–1925). Reprinted by Dover Publications (New York), 1962.

interval in monocular vision." In other words, when binocular vision is employed, the precision of judgment in the third dimension compares favorably with measurements of visual acuity.

The purpose of the present experiment is to measure the precision of depth perception (essentially the experiment reported by Helmholtz) and to study the relative importance of certain kinds of cues used in judging depth. In particular, we will measure the precision of depth judgments under three conditions: (1) Under binocular viewing, keeping the head fixed in position; (2) Under monocular viewing, keeping the head fixed in position; and (3) Under monocular viewing, with liberal head movements in order to produce monocular parallax, which is the differential apparent displacement of objects at different distances from the eye when the head is rotated.

APPARATUS

A version of the Howard-Dolman apparatus is employed (see Figure 8-1). The subject looks through a horizontal slit in a black screen at three vertically suspended, thin, black rods, which appear against a plain white background. The reduction screen limits the subject's field of vision to the white background and to the top portions of the three vertical rods. Two of the rods are fixed in position about midway between the black screen

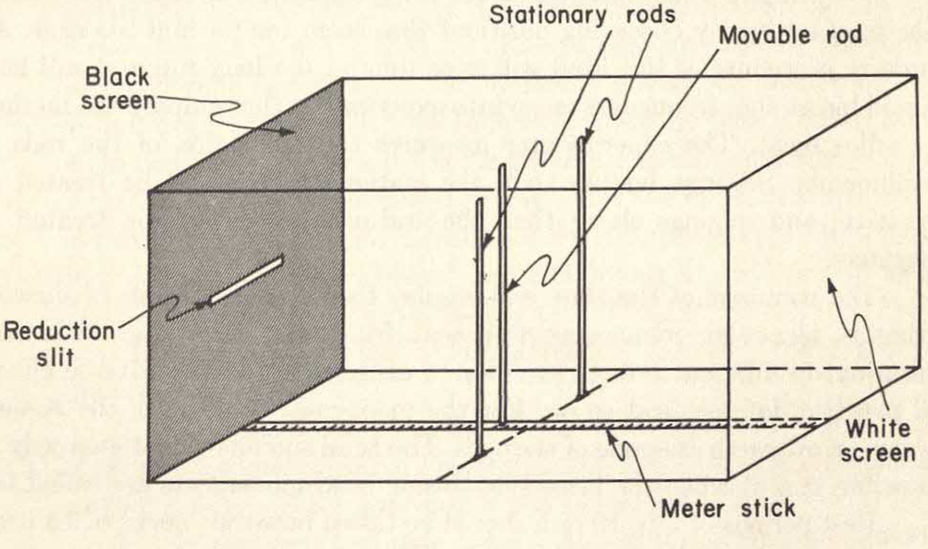

FIGURE 8-1. A simplified version of the Howard-Dolman apparatus.

and the white background field. The third rod is seen between the two stationary rods, but provision is made so that its distance from the subject is continuously adjustable, ideally by the observer. The distance between the movable rod and the stationary rods is measured by means of a meter stick.

PROCEDURE

The subject sits at a distance of about 4.5 ft from the stationary rods, or far enough away so that no background objects are visible other than the white screen. The exact distance from the eyes should be measured, marked, and maintained throughout the experiment. In order to prevent head movements, the subject can keep his head fixed in a chin rest, or if this is not available he can sit with the back of his head held rigidly against a wall. The subject's task is to position the adjustable rod so that it appears as far away as the stationary rods.

After two or three practice trials in order to get accustomed to each of the three conditions of viewing, fifteen judgments are made. The experimenter should widely vary the starting position of the adjustable rod. Do not inform the subject about his settings until after the experiment and avoid giving clues of any nature.

The subject is advised to bracket his judgment, that is, to close in on the final setting by observing positions that seem too far and too near. An orderly procedure of this kind will save time in the long run and will help avoid biases that frequently creep into experiments that employ the method of adjustment. The experimenter measures the separation of the rods in millimeters. Settings farther than the stationary rods will be treated as positive, and settings closer than the stationary rods will be treated as negative.

The members of the class will employ the three conditions of viewing (that is, binocular, monocular with head fixed, and monocular with head rotating) in different orders, in order to cancel the possible adverse effects of practice, fatigue, and so on. For the monocular conditions, the subject wears an eyepatch over one of the eyes. The head should be kept as steady as possible, except when the large side-to-side head movements are called for.

Rest periods of 5 to 10 min should be taken between blocks of 15 trials in order to help offset fatigue.

TREATMENT OF THE RESULTS

Tabulate the results separately for each condition of viewing. Compute the arithmetic means of the separations between the stationary rods and the adjusted rod. Unless there is a significant constant error, the mean should lie in the vicinity of zero.

Compute also the standard deviations of the separations before leaving the laboratory. The standard deviation σ is computed by the formula:

$$\sigma = \sqrt{\sum_{1}^{n} \frac{(\bar{x} - x)^2}{n}} \tag{8.1}$$

where $\bar{x}$ is the mean of the separations, x is an individual setting, and n is the number of settings (15). The standard deviation serves as a measure of the discrimination. Normally it assumes a high value for monocular viewing, a lower value when parallax is allowed, and a still lower value when binocular cues are available. From the class tally, calculate the approximate relative magnitude for the three conditions. It will also be interesting to note the range of individual differences.

DISCUSSION QUESTIONS

1. The value of the standard deviation (or any other measure of variability, such as the average deviation) depends upon the distance of the observer from the rods. In order to compare directly the results from different experiments, the standard deviations should be converted, using trigonometry, to an angular measure that is independent of the distance. This measure is the difference in the convergence angles of the eyes (the so-called disparity angle) for the rod seen at distance S and distance $(S + \sigma)$. To calculate the convergence angle, it is necessary to know the interocular distance O (about $2\frac{1}{2}$ in.) as well as the distance S from the observer's eyes to the object viewed (see Figure 8-2). In terms of the disparity angle, how do the results compare with the usual outcome?
2. Comment on any constant errors that appear to be significant. Students who know how may want to test the reliability of the constant errors by means of an appropriate statistical procedure.
3. In the report explain briefly the nature of the cues provided

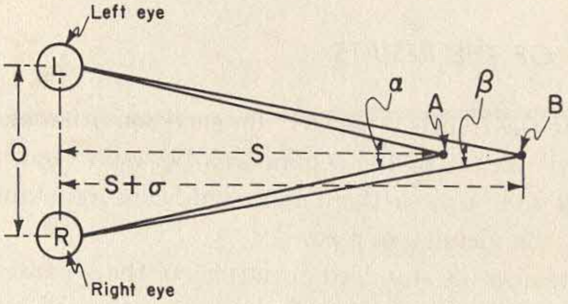

FIGURE 8-2. *Showing the convergence angles.* The convergence angles α and β are the angles by which the eyes (L and R) must converge to fixate the points A and B, which lie directly ahead of the subject. By trigonometry

$$\tan\frac{1}{2}\alpha = \frac{O}{2S} \qquad \text{and} \qquad \tan\frac{1}{2}\beta = \frac{O}{2(S+\sigma)}$$

The disparity angle is defined as the difference between these two angles.

A simpler way to measure the convergence angle is to regard the interocular distance O as an arc of a circle whose center is A (or B) and whose radius is S (or $S + \sigma$). The angle α equals O/S radians or, since 1 radian = 57.3°, the angle α equals $(60 \times 60 \times 57.3)O/S$ when measured in angular seconds.

by head movements and stereopsis in the perception of depth. What other cues could be utilized in making the judgments with the Howard-Dolman apparatus?

4. Can this measurement of depth discrimination be thought of as a measurement of a difference threshold? Can one speak meaningfully of a Weber fraction here?

9

Perceiving Direction of Movement

INTRODUCTION

Perception is often characterized by its ambiguity. A large number of physically distinguishable events in the environment may produce equivalent stimulation in the observer. For example, the retinal projections of a tilted circle and an upright ellipse may have the same shape and size. The famous reversible staircase and the Necker cube are other examples. What the person perceives under these conditions cannot be predicted simply by the geometry of the image cast on the retina, and, consequently, one of the problems of perception is to specify the factors that determine the perceptual outcome when stimulation is ambiguous.

A good example of the ambiguity of perception was provided by Wallach. Imagine a straight stripe moving in uniform direction and velocity behind a circular reduction window (see Figure 9-1A). In the absence of other information, there is no way for an observer to know the direction of the real movement of the line. Horizontal movement and vertical movement will, for example, produce the same temporal pattern of stimulation on the retina. At a given time the perceiver will, of course, see the line moving in some specific direction. The perceived direction (see Figure 9-1B) may or may not correspond to the real direction of movement, and characteristically the perception actually shifts, sometimes with almost discon-

For additional information see pp. 403–423 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

certing frequency, from one direction to another. Occasionally, the line may even "break up" and portions of it appear to move in different directions at the same time.

Wallach studied the conditions that favor seeing one direction of movement rather than another. In this experiment we will attempt to reproduce some of his observations, and when possible to measure some of the effects.

APPARATUS

See Figure 9-1F. An endless belt constructed of chart paper and sus-

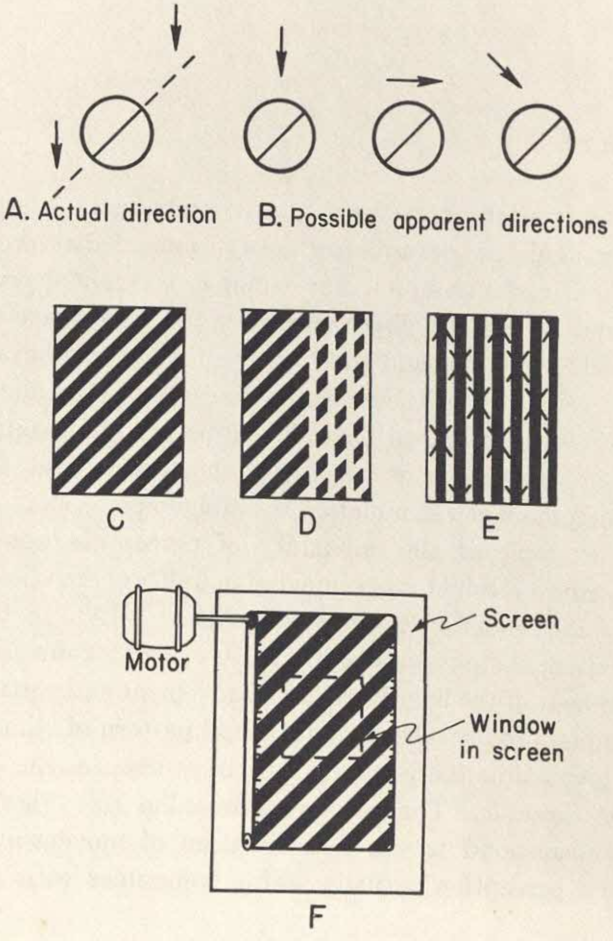

FIGURE 9-1. Apparatus.

pended vertically on sprocket rollers is driven by a variable-speed motor. Three kinds of paper are used: one having diagonal black stripes (Figure 9-1C), one having diagonal stripes that are half black and half red (Figure 9-1D), and one having vertical stripes (Figure 9-1E).

In this experiment, the reversals in perception often occur so rapidly that there results the problem of how to record the amount of time that a given direction is perceived. One solution is to provide the observer with two or three switches (each switch corresponding to a possible perceived direction) which operate a polygraphic event recorder. This will permit a continuous record of the perceptual events as they occur over a period of time.

If event recorders are not available, the experimenter can, upon instructions from the observer, record the perceived direction at regular intervals, say, every 2 sec, and a metronome can be used to mark off the intervals.

The moving stripes are viewed through apertures in a screen, which makes invisible all but a portion of the moving paper. Apertures of various shapes (for example, circular, rectangular, square) are used in different parts of the experiment.

PROCEDURE

1. Moving plain stripes (Figure 9-1C) are first viewed through a circular aperture. The task is to observe the apparent direction or directions of movement and to note the changes that occur over time. Is there a tendency for a given direction to predominate? Does the figure ever appear to lose its unity, different parts seeming to move in different directions at the same time?

2. The figure is next viewed through a square aperture. This tends to restrict the apparent direction of movement alternately to the horizontal and vertical. Does either kind of movement tend to predominate? Try to measure the proportions of time the different directions are observed. Also try to measure the rate at which reversals of direction occur as a function of time.

3. The figure is viewed through a narrow rectangular aperture, whose long side lies horizontally (or vertically). Does this shape tend to constrain the apparent direction of movement? When the rectangular aperture is rotated through 90 deg what happens to the apparent direction of move-

ment? Can one formulate a generalization concerning the constraining effects of the properties of the aperture on the apparent direction?

4. The direction of apparent movement depends on the figural character of the whole stimulus—that is, the moving stripes and the aperture through which it is viewed. It also depends to some extent upon temporal factors. For example, simply fixating the figure for a time tends to produce a fairly rapid fluctuation in apparent direction. The following may prove an interesting experiment. The figure consisting of vertical stripes (Figure 9-1E) is viewed for a few minutes through the square aperture; then the diagonal pattern (Figure 9-1C) is quickly placed into the apparatus and is viewed through the square aperture. Is there a tendency to see movement in any particular direction? Attempt to measure the effect as a function of time after the original fixation.

5. Insert the figure showing black and red diagonal stripes (Figure 9-1D) and view it through the square aperture. Note that the difference in color tends to restrict the apparent direction to the vertical. With continued fixation, however, there is a growing tendency to perceive a reversal. Horizontal movement would imply that stripes must change color as they pass from one side of the field to another. To many observers the horizontal direction does appear and the stripes appear not to change color but rather to pass beneath a transparent red surface. Or sometimes under these conditions, the black and red stripes become the perceptual ground, and the white stripes now become the moving figure. The black and red stripes are in this interesting case seen as stationary, "solid," and slightly behind the white "figure."

6. To what extent, if any, can the apparent direction of movement be voluntarily controlled? Investigate.

7. Experiment with several other apertures having more complex shapes (for example, a cross-shaped aperture). Can apparent movements having different directions ever be observed simultaneously? What do these observations imply about the role of eye movements as determinants of apparent direction?

8. Afterimages of seen motion may be observed. Fixate for a few minutes the moving stripes without the reduction aperture, then stop the belt but continue to fixate it. Observe the properties of the resulting afterimage. This experiment may be repeated using an aperture that constrains the apparent direction of motion. Is the apparent direction of the aftereffect related to the apparent direction during fixation?

RESULTS AND DISCUSSION

In the report, summarize briefly the observations made. Whenever possible, prepare graphs of whatever quantitative measurements proved possible.

Often it is useful to plot the data in cumulative form. For example, if the purpose is to learn whether the rate of fluctuation in perception changes with continued fixation, one can cumulate the number of fluctuations and plot the cumulated number as a function of time. Such a plot will frequently smooth out local irregularities in the function and display the over-all form of the function. Thus, if the rate of fluctuation does not change, the cumulative function should approximate a straight line whose slope indicates the average rate of fluctuation. If, on the other hand, the rate of fluctuation speeds up with prolonged fixation, the slope of the cumulative function will increase, that is, the function will accelerate positively, and vice versa. On this kind of plot, it is sometimes possible to observe over-all trends that might otherwise go undetected.

10

Size Constancy and Emmert's Law

INTRODUCTION

Everyone has had the experience of looking at a bright light and then seeing for a few moments a shadowy replica of it everywhere. The apparent size of this afterimage depends upon the distance between the observer and the surface onto which the afterimage is "projected." When the surface is close, the image looks relatively small, and as the distance is increased, the image appears to grow larger in size. This phenomenon receives quantitative expression in Emmert's law, which states that the apparent size of an image grows in direct proportion to the distance of the surface on which it is projected. The purpose of this experiment is to study Emmert's law by means of two different psychophysical procedures.

It has been argued by some that Emmert's law is really a special case of the law of size constancy, even though at first glance the two laws may seem to stand in opposition. Size constancy implies that an object tends to retain its apparent size as the distance from its observer is varied; Emmert's law says that the apparent size of the afterimage does change with changing distance. However, as the distance of a *real* object is increased, the size of the retinal image that it produces decreases. The apparent size depends, therefore, upon these two factors: (1) the size of the retinal image, which is inversely proportional to distance and (2) the distance of the object.

For additional information see pp. 480–491 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

The retinal size of an afterimage, on the other hand, has a fixed size, and its apparent size should, therefore, vary directly with its apparent distance.

In other words, size constancy is expressed by the formula

$$S = k\,R\,D \tag{10.1}$$

where S is the apparent size, R is the retinal size, and D is the distance of the object. Under ordinary conditions of viewing, if an object's distance D is doubled, the linear aspect of the retinal image R is halved and the object appears not to change in size (to the extent, of course, that size constancy really holds).

If, however, R is fixed and D is allowed to vary (as is the case with afterimages) then we expect the apparent size S to grow with the distance D. This hypothesis will be studied by the two procedures outlined.

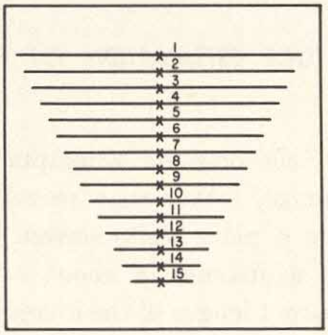

FIGURE 10-1.

EXPERIMENT 1. MATCHING THE SIZE OF THE AFTERIMAGE

The materials include a large white screen (about 30 in. by 30 in.) whose distance from the observer can be varied from about 1 ft to about 12 ft. This screen is the projection screen. On its surface lies a series of lines whose lengths range from large (at the top of the screen) to small (at the bottom), approximately as shown in Figure 10-1. Each line has a fixation point at the center and a number to identify it. The observer tries to determine by rapid successive fixation the line that most closely matches the apparent length of his afterimage.

The afterimage is produced by fixating a horizontal white line on a black screen, placed at a fixed distance from the subject (3 ft). The white line is about 3 in. long and about ⅛ in. thick. At its center lies a fixation point. The point is fixated (keeping the head and eyes very steady) for about a minute, so as to produce a strong afterimage. The dark afterimage is then projected onto the white screen, and the attempt is made to find a line of nearly equivalent length. From time to time it will be necessary to fixate the white line to strengthen the afterimage.

Follow this procedure for six different locations of the projection screen, for example, at 1, 2, 3, 6, 9, and 12 ft. Make the order of these distances irregular, and measure the image size several times at each distance. Use tape measures for accurate determination of the distances from the subject's eyes to the projection screen. Great care should be taken in measuring this distance when it is about 1 ft because a small error here will have a large apparent effect on the results. The subject's head should be fixed in place with a chin rest, or else the back held rigidly against a wall.

EXPERIMENT 2. MAGNITUDE ESTIMATION OF THE SIZE OF THE AFTERIMAGE

For this experiment, the observer attempts to estimate numerically the length of the afterimage, rather than match it to comparison lines. Project the afterimage on a plain white screen. Begin by projecting the afterimage of the line at a distance of about 3 ft. Let some convenient number stand for the apparent length of the image at this distance. Attempt to assign numbers proportional to the size of the afterimage when projected at the other distances. In other words, use the method of magnitude estimation that is explained in Chapters 5 and 6. The order of the distances should, of course, be irregular. Make two judgments at each of six or seven distances according to directions from the laboratory instructor. To prevent bias, two sets of distances should be used — one set for one of a subject-experimenter pair, and another for the other member of the pair.

RESULTS AND DISCUSSION

Class results should be tabulated and averaged. Individual results should also be analyzed if they are sufficiently clear-cut (and they usually are in the case of the matching, provided good measurements of the distances were obtained). For the report, prepare three kinds of graphs: (1) show the matched length of the afterimage as a function of the projection distance;

(2) show the magnitude estimations (geometric means) of the afterimage as a function of the projection distance; and (3) show the magnitude estimations of the afterimage as a function of the matched length of the afterimage. Are the functions reasonably consistent with one another? How well are the functions predicted by Emmert's law? Discuss. Is there any alternative view to the proposition that Emmert's law is a special case of size constancy? Predict how the same experiments would come out if all cues to the distance of the projection screen were successfully eliminated, and explain the reasons for the prediction.

11

Apparent Movement

INTRODUCTION

The motion that is seen at the movies or on television provides an example of what is called "apparent movement" because the eye is exposed to a series of static shots, separated by short intervals of time, rather than to continuous real motion. The study of apparent movement has played an interesting and important role in the history of experimental psychology.

In this experiment we will study a basic type of apparent movement known as "beta movement." Beta movement is seen when a very brief visual stimulus a occurs at location A, and after a brief pause another stimulus b occurs at location B. Movement is observed from A to B. A variety of factors determine whether movement is seen. Among them are:

The Pause between the Stimuli (p). This factor is probably the most important variable. If the pause between the stimuli is very brief (less than about 30 msec), a and b appear as simultaneous events; if the pause is too long (greater than about 400 msec), one sees a mere succession of the stimuli a and b, without movement. Between these extremes there is a pause that produces an "optimal movement." Actually, the length of this pause is difficult to determine with precision, since there is usually a fairly broad range of pauses within which movement is seen.

The length of the pause p necessary for optimal movement depends to

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For additional information see pp. 510–515 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

some extent upon other stimulus factors, such as the distance s between A and B, the intensity i of the stimuli, and the duration of the events a and b. Some of these variables are discussed briefly.

There is a value of p longer than the value that produces optimal beta movement and shorter than the value that produces succession that is said to give "phi movement"—a kind of pure "flash" movement that does not seem to involve the movement of objects. "Partial movement" may be observed at values of p longer than those that produce phi movement and shorter than those that produce pure succession. For example, the stimulus a may appear to move slightly in the direction of b, but there is no continuity of movement from a to b.

The Distance between the Stimuli (s). As the distance s between the stimuli is increased, the value of the pause p must be increased for optimal movement.

The Intensity of the Stimuli (i). As the intensity i of the stimuli is decreased, the pause p for optimal movement increases, keeping s constant. As i is increased, s increases for optimal movement, keeping p constant.

Korte suggested the following equations to relate the three variables i, s, and p for optimal movement:

for constant i:

$$p = ks \tag{11.1}$$

for constant p:

$$i = ks \tag{11.2}$$

for constant s:

$$i = k/p \tag{11.3}$$

but these simple equations (known as Korte's "laws") are not to be understood as representing accurate mathematical descriptions. They should rather be thought of as first-order approximations whose exact form is still a question for experimental investigation.

The Relative Intensities of a and b (i_a and i_b). It is reported, for example, that if i_b (the second of the two stimuli) is sufficiently more intense than i_a, the movement occurs in the direction from B to A, rather than from A to B. This "reverse" movement is known as "delta movement."

Other Stimulus Variables. Other stimulus variables, such as the shape and size of the stimuli, affect the apparent movement in various ways. To some extent, for example, the variable of size and intensity can be traded one for the other to produce the same effect.

Observer Variables. The class of observer variables is composed of rather vaguely understood but highly significant factors, having to do with the attitude or "set" of the observer and also with his past history. For example, some observers experience the apparent movement more easily than others; with repeated exposure, most observers see movement more and more readily. It has been shown that a "literal" or "analytic" attitude is unfavorable to the perception of apparent movement. Thus, "meaningful" apparent movement (the kind seen in motion pictures) is far more readily perceived than the movement of simple spots or lines.

APPARATUS

The stimuli in this experiment are small neon lights, housed in short metal tubes that are mounted on a meter stick. The tubes can be moved along the track of the meter stick in order to vary the distance s between the two lights. Neon lights are used because they have a rapid rise and

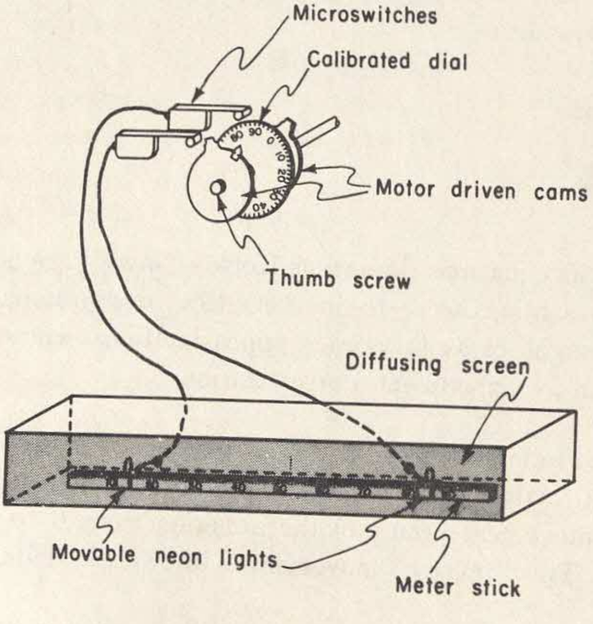

FIGURE 11-1. Apparatus for the production of apparent movement.

decay time. The lights can be activated by an electronic interval timer or by a simpler timing mechanism.

The meter stick supporting the lights is mounted inside a long box. One side of this box is a diffusing Plexiglas screen through which the lights are viewed. The size and shape of the lights can be determined by masks in front of the lamp housings. To control the intensity of the fields, neutral density filters can be placed in front of the lights.

The timing mechanism can be a synchronized motor that revolves two cams that open and close a pair of microswitches. Each cam closes its microswitch for about 20 msec at a time. The time between the flashes is varied by adjusting the relative positions of the two cams. The value of p in $\frac{1}{100}$ sec is read from a circular dial set in the shaft that revolves the cams. Figure 11-1 shows the entire apparatus.

PROCEDURE

Work in a dark room. The observer is first dark-adapted for a few minutes. The distance between the observer and the lights box should be kept constant (about 6 or 8 ft) throughout the experiment. The fields should be circular and about 0.25 in. in diameter.

Begin with the unattenuated lights, and let the distance between them be about 1 ft. The pause p between the lights is varied systematically from very short (giving simultaneity) to very long (giving succession). Try to determine the threshold for simultaneity of the stimuli, the pause that produces optimal movement, the pause that produces phi movement, and the threshold for succession of the stimuli. Follow the same procedure for other values of s, both shorter and longer than 1 ft, covering as large a range as practicable. These are not easy judgments to make. They should be preceded by plenty of practice and they should be undertaken very systematically but in a relaxed frame of mind.

The procedure is then reversed. Set the pause p to about 60 msec, and vary the distance between the two lights. Make the judgments for several representative values of p. In the report, attempt to show (for example, with appropriate graphs) whether or not your experiment corroborates the general function that is said to relate the variables s and p.

Next, attenuate the intensity of the field with the neutral density filters, and by adjusting the pause and/or the distance try to verify the functions that supposedly relate p and i, and s and i. If there is not enough time left to do both of these experiments thoroughly, let one of the observer-experimenter team work on one relation and the other on the other relation. It may also prove interesting to try to observe delta movement and to investigate how stimulus size and shape influence apparent movement. Interesting as many of these variables may be, however, the student is urged to concentrate his efforts on the exploration of one or two basic variables, especially the relation between p and s. The experiment is sufficiently difficult that repeated measurements will probably have to be taken until a reliable result begins to appear.

DISCUSSION QUESTIONS

1. Compare the outcome with the usual findings and particularly with Korte's laws.
2. What significance did apparent movement have in the origins of Gestalt psychology?
3. What is the role of eye movements in the perception of apparent movement?
4. What problem does apparent movement pose for the physiological psychologist?

12

The Tachistoscopic Perception of Verbal Patterns

INTRODUCTION

A commonly used device in the study of perception is the tachistoscope. It is essentially a timer—like a shutter—that limits a visual presentation to a very brief exposure. Many experimenters have employed a tachistoscope for the purpose of determining the shortest exposure that is necessary for perceiving something—for example, identifying the elements in a visual display.

Early in this century, Cattell, using a tachistoscope, showed that isolated letters take more time for recognition than do letters forming words. More recently, Miller, Bruner, and Postman* hypothesized that the superior perception of letters in words results not from some property peculiar to words, but rather from the general statistical structure of the language. To test this hypothesis, they composed sequences of eight letters that do not form true words but contain, to varying degrees, the same sequences as commonly found in the language. These "pseudo words," as they were called, were of four kinds and were composed according to definite rules:

1. *Zero-order approximation to English.* Letters were selected at random from the alphabet, each letter having an equal chance of being selected in the eight-letter sequence. Example: *XOLNPGDC.*
2. *First-order approximation to English.* Letters were selected on

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*Familiarity of letter sequences and tachistoscopic identification, *Journal of General Psychology* (1954), *50,* 129–139.

the basis of their frequency of occurrence in the language. One way to generate such sequences is to select letters from English prose by means of a table of random numbers. Example: *IORNETEI.*

3. *Second-order approximation to English.* Letters were selected in pairs on the basis of their frequency in the language. Such sequences can be generated from English prose as follows: If the first letter is *C*, one looks for the next occurrence of *C* (but not a *C* that ends a word) and records the first letter following *C* (say *O*). Then the letter immediately following the next occurrence of *O* is selected, and so on until a sequence of eight is complete. Example: *COLLESER.*

4. *Fourth-order approximation to English.* These were constructed like the second-order class, except that they are based on the relative frequencies of four-letter sequences in the language. That is, the choice of the fourth letter is constrained by the preceding three letters. Thus, if the first three letters are *SHA*, one searches for the next occurrence of *SHA* and records the letter following the *A*, say *N*. One then proceeds to record the letter following the next occurrence of the sequence *HAN*, and so on. Example: *SHANGING.*

The various types of sequences were presented for different durations, and the observer's task was to write in order as many of the letters as he could. The main results (see the accompanying table) were: (1) the longer the exposure duration, the more letters correctly identified in the proper place; that is, a letter can be considered correct only if it appears in the correct space on a score sheet having eight spaces; and (2) the greater the contextual constraint, the higher the recognition at all durations of exposure. The authors accounted for these findings in terms of the statistical redundancy of the language. A person's verbal habits reflect the characteristics of the

PERCENTAGE PLACEMENT SCORES FOR FOUR SETS OF PSEUDO WORDS AT FIVE EXPOSURE DURATIONS
(from Miller, Bruner, and Postman)

Exposure Duration (msec)	*Order of Approximation to English* 0	1	2	4
10	5.5	10.8	10.7	12.6
20	19.6	25.7	27.3	37.1
40	31.6	37.8	46.6	57.4
100	36.9	43.0	59.5	70.1
500	49.0	66.2	76.2	91.0

language; that is, a sequence of letters from the language to some extent "predicts" the next item in the series.

APPARATUS

The pseudo words are projected from slides onto a white screen (the slides should be of fairly uniform brightness and contrast). On the screen is a fixation spot. The exposure duration is regulated by means of a calibrated variable-speed shutter. The contrast between the letters and the background should be fairly low. The main reason for varying the exposure time is to produce a large range of placement scores. This will be an effective means only if the contrast is sufficiently low.

Four sets of 15 pseudo words are used, one set each for zero-order, first-order, second-order, and fourth-order approximations to English. All 60 words are exposed for four durations (10, 25, 60, and 500 msec suggested), making a total of 240 presentations. Scoring sheets having eight blanks for each item should be made available in advance.

PROCEDURE

Several persons can serve as subjects simultaneously. They sit at a distance that makes possible clear vision of an entire word. The 60 pseudo words are scrambled in order and presented one by one for a duration of 10 msec. Each subject tries to write each of the eight letters in the correct spaces of the scoring sheet. Then the 60 words are rescrambled and exposed again, this time for 25 msec, the next time for 60 msec, and finally for 500 msec.

ANALYSIS OF RESULTS

Count the number of letters correctly placed for each exposure duration and each order of approximation to English. Prepare a 4 by 4 table relating the exposure duration and the order of approximation to English. Fill in the table with the *percentage* of items correctly placed (see, as an example, the previous table). From the table construct a graph, for a given order of approximation, relating the percentage of correct placements (ordinate) and the logarithm of the exposure duration (abscissa). The four functions (one for each order of approximation) should be plotted in the same graph so that they can be compared directly.

You may wish to compare your results with those of the class and with those of Miller, Bruner, and Postman, but the primary analysis should be done using group data. In order to interpret the results of this experiment, it is helpful to consider a few basic concepts from the field of information theory. The student is advised to consult the original experiment or some source dealing with this subject area.

From the point of view of information theory, the amount of information (in bits) carried by a symbol in a communication system is equal to the logarithm (to the base 2) of the number of possible alternative symbols. For example, let us say that the communication system is capable of sending only two (and equally likely) messages, "yes" and "no." In this case, the amount of information per symbol is 1 bit. If the system has four letters, the amount of information per symbol is increased (to 2 bits) because receiving the symbol enables us to choose from a set of four equally likely alternatives, rather than only two.

The 26 letters of the English alphabet (or 27 if the space is counted as a symbol) may be considered to comprise a set of possible messages. It is obvious, however, that the information carried by a letter in the English language is less than $\log_2 27$. The basic logarithmic formula for computing the information assumes that each symbol has an equal probability of occurring, but this is clearly not true for English prose. Actual counts of letters in English show that the probabilities of occurrence are different for different letters. Furthermore, it is clear that in English the occurrence of a given letter affects the probability of occurrence of the subsequent letters. The greater the extent to which this is true, the greater is the redundancy of the system, or in other words, the smaller is the average amount of information carried by a letter. It should be clear, therefore, that the information per letter in zero-order approximation is greater than that in first-order approximation, that the information per letter in first-order approximation is greater than that in second-order, and so on.

Without going into the technicalities, let it be said that the average information per symbol can be estimated for various approximations to English. One method, for example, relies on letter counts from representative samples of English prose for single letters, pairs of letters, triplets, and so on. On the basis of this and other kinds of analysis, Miller and his coauthors made the following estimates of the approximate amount of information per letter relative to zero-order English:

zero-order = 100 percent
first-order = 85 percent
second-order = 71 percent
fourth-order = 57 percent

When the correct placement scores were multiplied by the relative information per letter (as shown in the accompanying table), it appeared that the amount of information conveyed in a given exposure time was fairly constant, regardless of the order of approximation to English. Thus, it appeared that a person's perception of the tachistoscopically presented material can be accounted for in terms of his familiarity with the statistical properties of the English language.

Percentage Placement Scores Corrected for
Relative Amounts of Information per Letter
(from Miller, Bruner, and Postman)

Exposure	*Order of Approximation to English*			
Duration (msec)	0	1	2	4
10	5.5	9.2	7.6	7.2
20	19.6	21.8	19.4	21.2
40	31.6	32.2	33.1	32.7
100	36.9	36.5	42.3	40.0
500	49.0	56.3	54.2	51.8

The class results and the discussion should be based on the same kind of analysis of the data that was used by Miller, Bruner, and Postman. The entries in the first table are multiplied by the appropriate factor to correct for the amount of information per letter. The corrected values are then entered into a second table and plotted as a function of the logarithm of the exposure time.

DISCUSSION QUESTIONS

1. Compare the results of this study with those of Miller, Bruner, and Postman. Is the main thesis of this study necessarily invalidated if the percentage placement scores (the first table) disagree with those of Miller, Bruner, and Postman?

2. What stimulus factors, other than the exposure time, help to determine the percentage of correct placements?

3. What is the possible effect of practice on the correct placement scores? On the correctness of the hypothesis that the information conveyed per exposure is constant?

4. State any clear-cut alternative explanations for the superior perception of words (and higher orders of approximations to words) to that given by Miller and his coauthors.

13

Human Verbal Learning

INTRODUCTION

The search for an adequate, scientific description of human verbal learning has led psychologists to study many variables that influence the acquisition and retention of verbal material. These experiments are attempts to relate an *independent variable,* such as the number of items in the material to be memorized, and a *dependent variable,* such as the number of readings of the material needed for one errorless, unaided repetition. Since verbal learning may be affected by the learner's previous experience with words, many experiments use syllables that do not exist in the learner's language. These are called "nonsense syllables," and they usually consist of a vowel between two consonants.

The present experiments will study three well-known phenomena in the acquisition and retention of a repeated list of nonsense syllables. The first of these has to do with the serial position of a syllable in the list; the middle items in a list of syllables ordinarily take the longest to learn. The second concerns the relatively short time it takes to learn "vivid" syllables; no matter where they appear in the list, syllables printed in a distinctive color are rapidly learned and well remembered. Finally, we shall study one example of the influence of previous experience on learning a list of syllables. As long ago as 1885, Ebbinghaus reported that learning one order of a list

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For additional information see Chapter 23 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

of syllables facilitated learning a different order of the same syllables. Since the syllables in the two lists were the same, his procedure was called the "method of derived lists." Ebbinghaus stated his results in terms of the "saving" in time or trials to learn the derived list compared to the learning of the original list.

APPARATUS

Each pair of experimenters should have a memory drum, which is a device for presenting a list of syllables one at a time to a subject, and two pairs of lists of 11 nonsense syllables each. The mechanism of the drum is set so that 2 sec elapse between the disappearance of one syllable and the appearance of the next. This intersyllable interval is held constant in all of the experiments, since it is itself a variable that affects learning. One list in each pair is derived from the other by reversing the order of the syllables. One list has two syllables printed in red for vividness. The red items appear in one list for half the class and in the other for the other half.

PROCEDURE

One student is the experimenter and the other the subject for the first pair of lists, and the roles are reversed for the second pair of lists. The subject should not be permitted to see the list before the experiment begins. For this reason, the lists are not included in this book, but will be distributed at the beginning of the experimental session.

1. The subject should learn the first syllable list by the method of oral serial anticipation. The first time through the list (a trial), the subject quietly reads aloud the letters in each syllable. In each subsequent trial, the subject anticipates the next syllable by saying its letters aloud in the 2-sec interval between syllables. Allow 30 sec between repetitions of the list. Continue the trials to a criterion of one trial of errorless anticipation of each syllable. The experimenter should record the response of the subject on each trial and any other data that he feels is relevant and useful.
2. After a 5 min pause during which the subject should not repeat the syllables covertly, one additional trial gives a measure of memory in terms of the number of syllables correctly anticipated.
3. Use the same procedure with the derived list and keep a record of the same dependent variables. Include the pause and the test of memory.

4. Reverse the roles of experimenter and subject and repeat the procedure with the second pair of lists.

RESULTS

The raw data consist of the correct or incorrect anticipations of each syllable on each trial. From the raw data, the student should compute useful summary statistics such as the number of trials to learn the list to the criterion, the amount of time this takes (excluding pauses between trials), the number of the trial on which each particular syllable was first anticipated correctly, and so on. State the results concisely, but thoroughly.

The data should be presented in tables or graphs that relate dependent variables to independent variables in a way that provides answers to the questions raised by the experiment. For example, a graph that shows the number of incorrect anticipations as a function of the serial position of the syllable in the list will identify the effect of position on difficulty of learning.

The data of each pair of experimenters should be sufficient to show the effect of a syllable's position in the list on the difficulty of the syllable. Also, an individual subject's "savings" in learning the reversed list can be assessed by comparing the number of trials needed to learn the reversed list with the number of trials needed to learn the original list. The effect of vividness can be determined from the pooled data of the whole class, which should be made available. Compare the average performance on one list with the average performance on the same list having two syllables printed in red.

The details of the presentation of the results are left to the student.

DISCUSSION

Discuss the results in the light of your knowledge of verbal learning. What behavioral processes can account for the results? Comment on the problems that may arise when the performances of a single individual on two tasks are compared. Contrast this with the use of the average performances from groups of subjects. Discuss the concept of *difficulty*. Is *difficulty* a dependent or an independent variable? Feel free to discuss any other important aspect of the procedure or results.

14

Human Motor Skills and Transfer of Training

INTRODUCTION

The acquisition of motor skills, such as driving an automobile or playing the piano, poses the same analytical problems as learning a list of words or syllables. At a descriptive level, the acquisition of a skilled movement may differ from the acquisition of a list of syllables only in the physical form of the response and not necessarily in the underlying process. Many experiments have shown that motor and verbal learning are similar with respect to the independent variables of which they are a function. These exercises are a controlled investigation of the effects of two such independent variables: (1) the amount of practice of the skill and (2) previous experience with similar, but not identical, skills. The effects of previous experience with a *similar*, but not identical, skill are known as "transfer of training." Transfer may be positive (an aid) or negative (a hindrance).

We use nonsense syllables to study verbal learning because they presumably equate all subjects with respect to unknown and therefore uncontrolled effects of training prior to the experiment. For similar reasons, we will use the tracing of an outline seen in a mirror to study the acquisition of a motor skill.

APPARATUS

Each pair of students has a mirror-tracing apparatus consisting of a

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For additional information see pp. 733–743 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

mirror, a screen, and a set of clips on a baseboard to which outlines of figures may be attached (Figure 14-1). Arrange the screen and the mirror so that the subject can see the baseboard only in the mirror. Be sure that the subject's hand and pencil fit comfortably and fully under the screen. The figures to be traced are a square, a star, and an *8*. Each figure has a total perimeter of about 24 in.

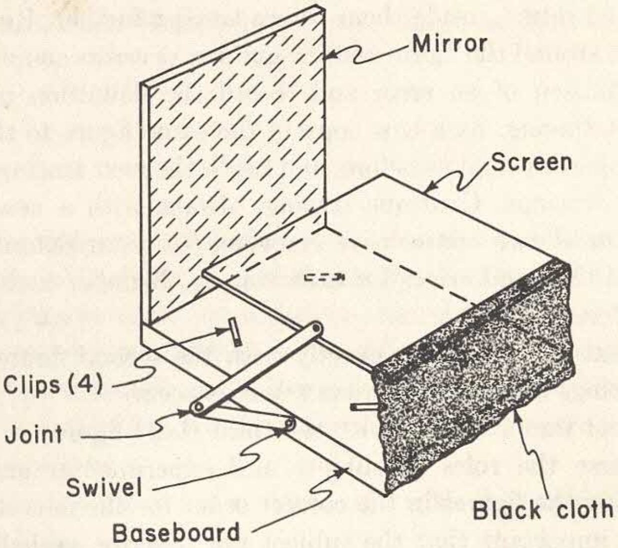

FIGURE 14-1. Mirror-tracing apparatus.

PROCEDURE

Each student will practice tracing all three figures in an order that will be assigned by the laboratory instructor before the experiment. The order will be one of the following three:

1. *8*, star, square
2. star, *8*, square
3. square, star, *8*

In order to measure the effects of specific kinds of previous experience, the class is divided into three groups, each of which follows one of the three orders.

After the order of practice has been given and the apparatus has been set up, proceed as follows with one student as experimenter and the other as subject:

1. Fix the first figure to the baseboard, with the arrow on the figure pointing to the mirror. Put the point of the subject's pencil within the lines of the figure next to the arrow. Instruct the subject to trace completely around the figure between the guide lines in the direction specified by the arrow as seen in the mirror. Whenever his pencil moves outside the guide lines, he should return inside them before tracing further. Record the time taken to trace around the figure and the number of errors committed. Choose a precise definition of an error and record the definition in your notes. After the first tracing, fix a new copy of the same figure to the baseboard, orient the subject's pencil as before, and begin the next tracing. Allow 1 min rest between tracings. Continue tracing, always with a new copy of the same figure, until two consecutive errorless (by your definition) tracings occur. Record time and errors for each tracing. Number each traced figure for future reference.
2. Repeat the procedure exactly with the second figure. Again, continue the tracings until two errorless tracings occur.
3. Repeat the procedure with the third (last) figure.
4. Reverse the roles of subject and experimenter and repeat the procedure using the figures in the correct order for the new subject.
5. It is important that the subject not describe verbally what he is doing as he traces. After both students have completed the experiments, however, they should question each other concerning the way in which each traced the figure. Did the subject, for instance, discover facts about mirror images that he *explicitly* used in tracing?

RESULTS

Make graphs of your data to show the course of acquisition of tracing each figure in terms of the two dependent variables, time and errors. Include the definition of an error that was adopted. If the acquisition curves appear to change for the second and third figures traced, the results should contain a summary of the changes. Try to distinguish quantitatively between changes in the shape of the acquisition curve and changes in the maximum level reached in the curve.

Transfer of training can be measured in the pooled data from the whole class by comparing the data from each of the three orders of tracing the figures. As one example, a comparison among the star-tracing performances in the three orders will show if the acquisition of tracing the star is affected by the prior tracing of either an *8* or a square. Other comparisons are possible, and they are left for the student to discover. Be careful to justify each comparison. Present a quantitative evaluation of transfer in each case.

Compare the data from the first and second subjects in each pair of students. Is there any transfer from merely observing another person trace a figure?

Compare males and females in terms of the acquisition of a particular figure.

DISCUSSION

Discuss the importance of the results for the psychology of motor skills and transfer of training. Would the improvements in the performance of a single individual on three successive tracings of the same figure be called transfer? Why or why not? What is the difference between transfer and acquisition? What is transferred? Of what variables might the amount of transfer be a function? Give specific examples from your own experimental data whenever possible.

Compare the acquisition of a motor skill with the acquisition of a list of nonsense syllables.

Observational learning—acquisition of a skill caused by watching another perform the skill—is an interesting but intricate and difficult topic. Appraise what you learned by observing your partner trace one of the figures. Discuss the difficulties in measuring observational learning; for example, what is an adequate control? Discuss the possible effects of knowledge of mirror images on mirror tracing performance. Try to state exactly what "knowledge" means in this context and the relation of knowledge to motor skills. Does this line of thought suggest what some psychologists mean when they distinguish between learning and performance?

15

Set and Performance

INTRODUCTION

The concept of *set* is roughly equivalent to a combination of readiness and expectation. The subject who is set is ready to respond appropriately to the next changes in the environment, and he expects the occurrence of certain events rather than others. In this sense, a set has two functions: (1) it limits the stimuli to which the subject is likely to attend and (2) it limits the responses that are likely to occur.

There are two kinds of experiments on set. One studies the effects on performance of specific previous performance. The set results from a successful mode of performance and is called "task-induced." The other kind of experiment studies the effects on performance of instructions given to the subject by the experimenter and is called "instruction-induced." The first experiment will study a task-induced set. The subject will work a series of arithmetic problems that can be solved by either a short or a long method, after he has practiced a series that can be solved only by the long method. Typically, subjects become set to use the long method through successful practice and continue to use it on the problems that could be solved by the short method. The second experiment studies the differences in verbal association times brought about by constraints on the required type of association.

For additional information see Chapter 3 and pp. 830–841 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

In a word-association experiment, the subject is given a stimulus word, and he responds with the first word, other than the stimulus word, that occurs to him. Kent and Rosanoff (1910)* showed that there is some regularity from subject to subject in the response words they give. For example, out of 1000 subjects asked to associate to "needle," 160 said "thread" and 58 said "eye." From these data, Kent and Rosanoff defined a useful statistic called "communality." The communality of a response is defined as the percent of subjects giving that response. Thus, for example, the communality of "thread" as a response to "needle" is 16 percent. Kent and Rosanoff published a list of communalities for responses to each of 100 words.

The word-association experiment has been modified by instructing (or setting) the subject to respond with a word that has a certain relation to the stimulus word. Such relations as antonym, part-whole, and verb-object have been used. When a particular relation is prescribed in advance of the stimulus word, the response is called a "constrained association." Typically, the reaction time for a given stimulus word is shorter for constrained association than for free, unconstrained association. If the constraint implies a response word of high communality, the reaction time is likely to be still shorter.

The three types of associations to be studied here are free, constrained, and communally constrained. In communally constrained associations, the instructions make likely a response of high communality. Often, of course, this will be the same response that is given in free association. Nevertheless a comparison of association times may be profitable.

SUBJECTS

Each student will bring an inexperienced subject to the laboratory. Do not give the subject any information about the experiment.

APPARATUS

For the first experiment, each experimenter will use the Luchins' water-jar problems on page 79. He should copy each problem in order onto separate, numbered index cards.

For the second experiment, a list of 60 words and a timer of the type

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*Kent, G. H., and A. J. Rosanoff, A study of association in insanity. *American Journal of Insanity* (1910), *67*, 37–96, 317–390.

used in Chapter 3 are necessary. Kent and Rosanoff give communality tables for each word. There are three types of relations: (1) free, in which the subject gives the first response word that occurs to him, (2) constrained, or (3) communally constrained, in both of which the subject gives the first *appropriate* response that occurs to him. Because we will want to compare the reaction times for these three kinds of associations, each subject will make free associations to each word, communally constrained associations to one half of the words, and constrained associations to the other half. The list of 30 words on page 80 is for constraints of less than 10-percent communality, and the list of 30 words on page 83 is for constraints of greater than 30-percent communality.

Association to one word may alter the next association to the same word. To control for this possibility, the order in which the subject makes the three types of associations will be different for each third of the class. One group of subjects will make communally constrained associations, then constrained associations, and then free associations. Another group will make free associations, then communally constrained associations, and finally constrained associations. The third group will make constrained associations, then free associations, and finally communally constrained associations.

PROCEDURE

Sit on the opposite side of the table from the subject. Do not let him see any of your materials.

Task-induced Set. Give the subject the card containing the first arithmetic problem. Explain that there are two jars, one holding 29 qt of water and the other 3 qt, and that he is to write down on the card how he would use the two jars to obtain exactly 20 qt of water. Let the subject think for a minute, then show him, if necessary, that he can fill the 29-qt jar and empty it into the 3-qt jar three times leaving 20 qt in the bigger jar. Show him that he should write $29 - 3 - 3 - 3 = 20$ as his solution.

Give the subject the card with the second problem. Explain that there are now three jars (21, 127, and 3 qt) and that he is to produce exactly 100 qt in one jar. Allow 2 min of work, then show him that the solution is $127 - 21 - 3 - 3 = 100$.

Now present the rest of the problems in order. Give no help. The subject should write out the whole solution in the form just shown. Save the cards for scoring later.

Instruction-induced Set. The dependent variable is reaction time—the time between your saying the stimulus word and the subject's saying the response word. Practice making this difficult measurement before starting the experiment. The timer should start coincident with your saying the stimulus word and stop coincident with the subject's saying the response word.

Read the following instructions to the subject:

> This is an experiment in word association. I will read a stimulus word to you, and you are to reply as quickly as possible with the first word that occurs to you, other than the stimulus word itself. Before reading each word, I will tell you the type of association you are to make. There are three kinds of associations: free, antonyms, and part-whole. If I say "free," reply with the first word that occurs to you. If I say "antonym," reply with the first antonym that occurs to you. If I say "part-whole," reply with the first whole or group of which the stimulus word is a part.
>
> I am going to record the time you take to reply. Be as quick as you can. Be sure to say the first appropriate word you think of.

Here are three associations for practice. Measure the reaction time to each of these before starting the experiment.

Type of Association	*Stimulus Word*	*Response Word*	*Reaction Time*
free	won		
part-whole	trout		
antonyms	bright		

Now have the subject associate to each of the words in the list. Record his response word and the association time.

RESULTS

Present an adequate summary of the results for the task-induced set. It may be useful to compare the results with those of the other members of the class. If you wish to discuss the verbal reports of the subject, these data appear in the results.

Compare the subject's reaction times for free and constrained and for free and communally constrained associations to the same word. Does communally constraining a response shorten the reaction time to a given word even when the subject gives the *same* response in free association? What is the effect of noncommunal constraints? It may be desirable to comment on particularly long reaction times.

Use the pooled results from all subjects to determine the degree of the generality of your own results.

In making each of the comparisons it is, of course, very convincing (and convenient) if every reaction time of one type is longer or shorter than every reaction time of a different type. However, if it seems necessary or desirable to present average reaction times in order to summarize the data, choose the most appropriate average. The geometric mean—or the median—is generally better than the arithmetic mean if the distribution of reaction times is skewed, that is to say, if there are a few particularly long reaction times. (See Chapter 3.)

DISCUSSION

Discuss the accuracy of the measurements of reaction time. What constant error(s) do they contain? What variable errors? Can you suggest a better method for measuring reaction time?

Discuss the reasons for the differences between communally constrained (and noncommunally constrained) and free associations to the same word. Are these differences significant? In what sense(s)? Are the effects of constraining to low communality responses consistent with the effects of constraining to high communality responses?

Discuss the role played by set in the results. Are there any differences between task-induced and instruction-induced sets either in the way they presumably operate or in the results they produce?

If the results differ from those previously reported in the experimental literature on set, discuss the variables that may be responsible for the differences.

LUCHINS' WATER-JAR PROBLEMS

Jars			
1	*2*	*3*	*Get*
14	163	25	99
18	43	10	5
9	42	6	21
20	59	4	31
13	83	28	14
56	90	12	10
43	93	20	10
8	61	6	41
24	52	3	22
19	42	3	17
23	49	3	20
15	39	3	18
28	76	3	25
18	48	4	22
14	36	8	6
19	42	4	15
29	3		20
21	127	3	100

Noncommunally Constrained Associations: Communality Less Than 10 Percent

Type of Association	*Stimulus Word*	*Response Word*	*Reaction Time*
ANTONYMS	eating		
	comfort		
	wish		
	citizen		
	sleep		
	anger		
	working		
	trouble		
	justice		
	hungry		
	afraid		
PART-WHOLE	man		
	window		
	foot		
	king		
	hand		
	whistle		
	city		
	tobacco		
	stem		
	music		
	house		
	fruit		
	priest		
	whiskey		
	hammer		
	thief		
	earth		
	doctor		
	bed		

Free Associations: Comprising the Sixty Constrained Associations in a Different Order

Stimulus Word	*Response Word*	*Reaction Time*
stem		
tobacco		
city		
whistle		
hand		
king		
foot		
window		
man		
lion		
cottage		
Bible		
yellow		
eagle		
cabbage		
hot		
up		
east		
day		
yes		
new		
out		
good		
above		
long		
high		
rough		
sour		
slow		
black		

FREE ASSOCIATIONS: COMPRISING THE SIXTY CONSTRAINED ASSOCIATIONS IN A DIFFERENT ORDER (Cont.)

Stimulus Word	*Response Word*	*Reaction Time*
soft		
dark		
afraid		
hungry		
justice		
trouble		
working		
anger		
sleep		
citizen		
wish		
comfort		
eating		
bed		
doctor		
earth		
thief		
hammer		
whiskey		
priest		
fruit		
house		
music		
steeple		
hinge		
elbow		
page		
fin		
finger		
girl		

COMMUNALLY CONSTRAINED ASSOCIATIONS: COMMUNALITY GREATER THAN 30 PERCENT

Type of Association	*Stimulus Word*	*Response Word*	*Reaction Time*
ANTONYM	dark	________	________
	soft	________	________
	black	________	________
	slow	________	________
	sour	________	________
	rough	________	________
	high	________	________
	long	________	________
	above	________	________
	good	________	________
	out	________	________
	new	________	________
	yes	________	________
	day	________	________
	east	________	________
	up	________	________
	hot	________	________
	girl	________	________
PART-WHOLE	finger	________	________
	fin	________	________
	page	________	________
	elbow	________	________
	hinge	________	________
	steeple	________	________
	cabbage	________	________
	eagle	________	________
	yellow	________	________
	Bible	________	________
	cottage	________	________
	lion	________	________

16

Experimental Control of Observing

INTRODUCTION

The observation and detection of signals have been studied from many points of view. Some studies have emphasized the relative consequences of detecting versus failing to detect a signal. Others have tried to find the smallest magnitude of a signal that is observed a certain percentage of the time. The approach in this experiment is to treat observing as a form of operant behavior that is reinforced by the detection of a signal.

The experimental technique was developed by Holland. His subjects pressed a button to illuminate briefly a dial and a pointer. The subjects were instructed to detect and report deflections of the pointer. Deflections occurred according to a schedule arranged in advance by the experimenter. Pressing the button that turned on the light was called the "observing response" because the deflections could not be seen unless the button was pushed. Holland found that the *rate* of pressing the button—the rate of observing—was controlled by the schedule on which deflections of the pointer occurred. Different schedules of deflections produced different patterns of rates of observing. For example, if deflections occurred regularly every minute (a fixed-interval schedule of deflections), the rate of observing was low immediately after a deflection had been detected, and the rate gradually increased as the time for the next deflection approached. If the interval of

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For additional information see Holland, J. B., Human vigilance. *Science* (1958), *128*, 61–67.

time between deflections was variable, the rate of observing was nearly constant (a variable-interval schedule of deflections). If the pointer was deflected after every 50 observing responses (a fixed-ratio schedule of deflections), the rate of observing was high with very slight pauses just after a deflection had been detected. If no deflections occurred for some time, the rate of observing decreased to a very low level (extinction). This experiment investigates the control of observing by several schedules of pointer deflections.

SUBJECTS

Each *pair* of students should bring one inexperienced subject to the laboratory.

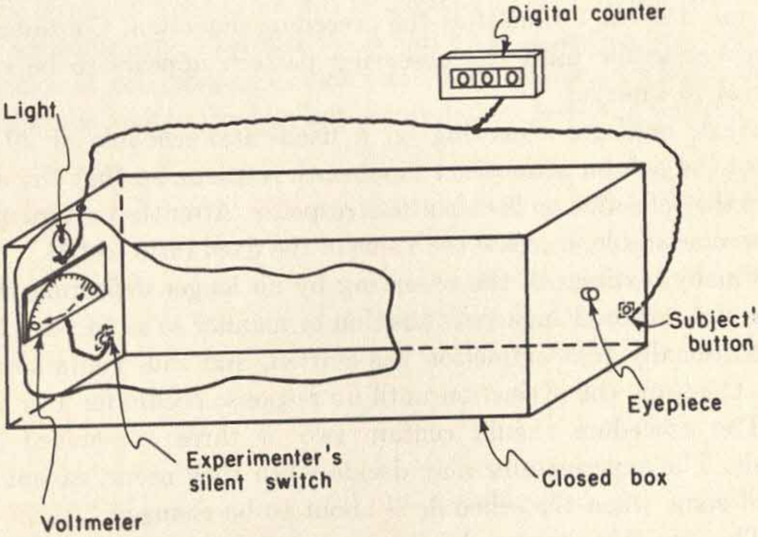


FIGURE 16-1. Observing-response apparatus.

APPARATUS

The subject will look with one eye into a dark box. Pressing a button briefly (approximately 0.2 sec) on the right side of the box lights a small lamp at the other end of the box. The light is sufficient for seeing the pointer, which is located directly below the light. Each press of the button also operates a counter on the outside rear wall of the box.

The experimenter can, by closing a silent switch, deflect the pointer. Figure 16-1 shows the entire apparatus.

PROCEDURE

Instruct the subject to look into the box and press the button two or three times. Explain that his task is to detect and report the pointer deflections he sees at the end of the box. Deflect the pointer. When the subject presses his button and reports that the pointer is deflected, immediately reset the deflection. Let the subject detect three or four deflections, then proceed with the experiment.

For 10 or 15 min, reinforce observing on a variable-interval schedule with an average interval of 30 sec. Before the experiment, write out a series of 8 or 10 time intervals whose average is 30 sec. When the subject reports a deflection, reset the pointer.

Next, without a pause, deflect the pointer on a fixed-interval schedule of 3 min, that is, 3 min after the preceding detection. Continue the fixed-interval schedule until the observing pattern appears to be stable from interval to interval.

Next, reinforce observing on a fixed-ratio schedule of 20 responses. Deflect the pointer after every nineteenth response so that the subject will detect the deflection on his twentieth response. After the pattern of observing has become stable, increase the value of the fixed ratio to 100.

Finally, extinguish the observing by no longer deflecting the pointer. Be careful not to change your position or manner so as to warn the subject unintentionally that extinction has started, and thus contaminate the results. Continue the extinction until no response occurs for 1 or 2 min.

The procedure should contain two or three announced 5-min rest periods. The experimenter may decide when they occur, except that none should come when the schedule is about to be changed.

The variable measured is the number of responses in short, equal periods of time. One student should deflect the pointer on schedule; the other should record the number on the counter every 10 sec. Do not reset the counter to zero during the experiment because responses may be lost during resetting. The number of responses between two readings can be obtained by subtraction.

RESULTS

The dependent variable is the rate of observing. In order to examine the rate of observing and its changes over time and with different schedules of deflections (the independent variables), plot a cumulative record of observing responses. On such a record the abscissa is time and the ordinate is the cumulated number of responses. For each detection of an actual deflection make an identifying mark on the record. Label each record with the initials of the subject and the schedule of reinforcement that produced the record.

In making the graphs it may be advisable to separate the performance during transitions between schedules from the final, steady-state performance on a schedule.

DISCUSSION

Discuss the control of an observing response by the schedule of pointer deflections in terms of what is known in general about reinforcement and schedules of reinforcement. Consider the definition of observing as a response and the function of detecting as a reinforcer. What problems would arise if the subject did not look in the box but continued to press the button?

17

Pavlovian Conditioning of the Galvanic Skin Response

INTRODUCTION

Sudden, intense, or emotionally charged events, such as receiving an electric shock, are known to cause a drop in the electrical resistance of the skin. This change in resistance is the so-called galvanic skin response, or the GSR. The eliciting stimulus, for example an electric shock, is called the "unconditioned stimulus" (US); the drop in resistance, the "unconditioned response." The elicitation of the GSR by the shock is called an "unconditioned reflex," signifying that it takes place reliably and without benefit of any training of the organism.

Pavlovian conditioning is a technique for imparting to a neutral stimulus, such as a light, the power to elicit a response, such as the GSR, by presenting the light together with the shock a number of times. The light comes to elicit a change in resistance similar to the change originally elicited by the shock. The light is then called a "conditioned stimulus" (CS), and the GSR to the light a "conditioned response." The light–GSR relation is called a "conditioned reflex."

In order to conclude that *paired* presentations of light and shock are necessary for conditioning, it must be shown that neither the presentation of the light alone nor the presentation of the shock alone establishes a conditioned reflex to the light.

For additional information see pp. 137–159, 541–572 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

Pavlovian conditioning is gradual. The magnitude of the GSR to the light alone increases with the number of paired presentations. And, in addition to the magnitude of the GSR, there is an increase in the percentage of trials on which the GSR is elicited by the light. The rate of conditioning and its final level depend, among other factors, on the duration of the CS–US interval, which is the time, in any pairing, between the onset of the light and onset of the shock. Experiments have shown that conditioning is most rapid if this CS–US interval is 0.5 sec, and progressively less rapid for CS–US intervals progressively less than or greater than 0.5 sec. ("Backward" conditioning—the US before the CS—appears to be virtually impossible.) This experiment will study these relations.

After conditioning, the magnitude of the conditioned response decreases on successive presentations of the CS without the US. This process, called "extinction," usually proceeds more rapidly with short pauses (massed trials) than with longer pauses (spaced trials) between presentations of the CS. Moreover, after a particularly long pause between presentations of the CS alone, the magnitude of the response is usually larger than the magnitude of the responses before the pause. This sudden increase in the magnitude of the response is called "spontaneous recovery." This experiment will study spontaneous recovery and the difference between massed and spaced extinction.

SUBJECTS

One student will be the subject, the other the experimenter, and then vice versa.

APPARATUS

Each pair of students will have a recording galvanometer, a device for recording continuously the subject's skin resistance. Attach the input of the galvanometer to the palm of the subject's left hand. Seat the subject in front of the stimulus panel and firmly attach the shock electrodes to two points on the right hand. Be sure that the subject can see the light. See Figure 17-1 for the entire apparatus.

The sequence of light and shock onsets and their duration are regulated by a timing device consisting of cams driven by a synchronous motor. Adjust the timing device for the desired interval between the CS (light)

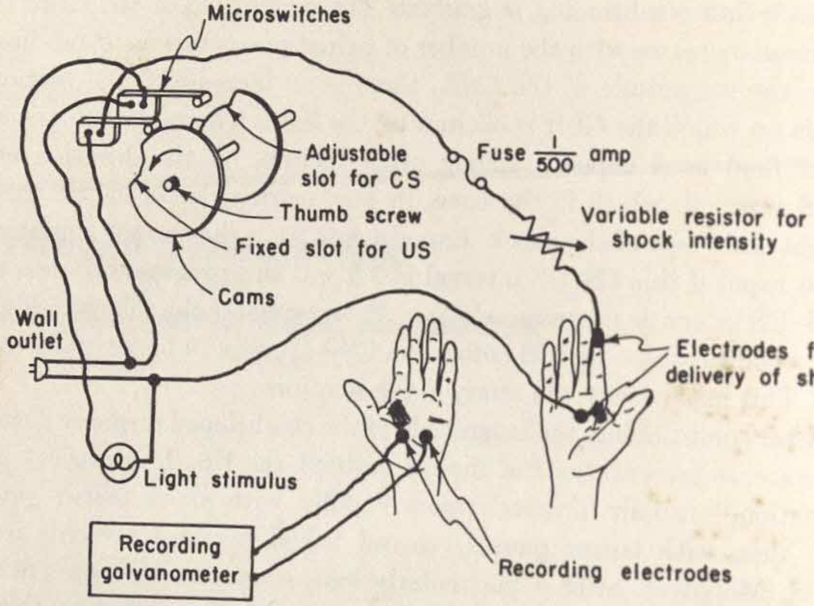


FIGURE 17-1. Apparatus for the conditioning of the galvanic skin response.

and the US (shock). This adjustment also determines the interval between trials.

The instructor will assign to each experimenter a CS–US interval for conditioning (0, 0.5, 1.0, 1.5, or 3.0 sec) and an interval between presentations of the CS for extinction (15 or 60 sec).

PROCEDURE

1. Put the galvanometer out of sight of the subject. Begin the experiment by presenting several shocks. Adjust the setting of the variable resistor to where the subject finds the shock distinctly unpleasant, but not extremely painful. Note the level of the unconditioned GSR and adjust the galvanometer to center the needle. Always write on the record what the procedure has been.

2. After a short pause, present the light alone five times. Again, note the change in the GSR, if any.

3. Begin conditioning by pairing the CS (light) with the US (shock) at the assigned CS–US interval. Present the CS alone on every fifth trial, marking these on the record. If there is a conditioned response, that is, a drop in the skin resistance, on the fifth trial, present the CS alone again.

Continue with blocks of four conditioning trials and one or two test trials until there is a conditioned response on two successive test trials.

4. Immediately start extinction: Continue to present the light alone with no shock. Disconnect the shock by removing the electrical connection at the timing device. Leave the electrodes on the subject's hands. Space presentations of the light either 15 or 60 sec apart according to which value is assigned. Mark the start of extinction on the record. Do not tell the subject that extinction has begun.

5. After response to the light alone becomes very small or disappears, pause for 10 min with the subject still connected to the apparatus. Then present the CS alone for five additional trials.

6. Subject becomes experimenter and vice versa. Repeat the procedure using the CS–US interval and the intertrial interval in extinction assigned to the new experimenter.

RESULTS

A conditioned response to the light may appear on training trials before the onset of the shock and on test trials when the shock is omitted. Are there any differences between these two sorts of conditioned responses? Are there any differences between the conditioned responses to the light and the unconditioned responses to the shock?

Plot a graph for the subject showing the magnitude of the conditioned responses to the CS alone as a function of the number of paired presentations of CS and US. Show also the magnitude of the responses to the US alone and to the CS alone before the start of conditioning. Plot another graph showing the decline in the magnitude of the response during extinction. Include the response after the 10-min pause. Indicate the CS–US interval and the intertrial interval in extinction of the graphs.

From the pooled data for the entire class, draw a graph to show the CS–US interval that gives the most rapid conditioning. Also compare the extinction curves obtained with 15 and 60 sec between presentations of the CS alone.

Does the CS–US interval during training affect the course of extinction or the magnitude of spontaneous recovery?

DISCUSSION

Compare the findings to the classical findings in GSR conditioning. What factors may account for the differences? How might they operate?

Pavlovian conditioning is often described as "stimulus substitution," the simple substitution of the CS for the US in the unconditioned reflex. Do the data infirm or confirm this view? What alternative formulation can be offered?

In what sense is "spontaneous recovery" spontaneous? What characteristics of time as a stimulus are useful in analyzing spontaneous recovery? Is the analysis similar for memory and reminiscence?

18

Imprinting

INTRODUCTION

In reference to the process of imprinting, a naturalist, Konrad Lorenz, wrote: "in a certain group of instinctive acts where the motor response is innate while the releaser is not, the acquiring process is basically different and cannot, to my mind, be identified with learning."* This acquiring process is said to be distinguished from "true learning" on the basis of two characteristics: it can occur only during a brief critical period in the life of the individual; and, once it has occurred, it is irreversible. Accordingly, imprinting has been defined as a process whereby a stimulus irreversibly acquires the capacity, during a critical period in the development of the organism, to elicit an innate response.

Certain aspects of the behavior of young precocial birds typify this process. When, for example, a graylag gosling is adopted by human beings immediately after hatching, all the behavior patterns that would normally be directed toward the parent geese are directed, instead, toward the human beings. The goose peeps "pitifully" if the human walks away and soon follows him about "religiously." The goose's behavior does not change "in the least even if it is later kept for years with other members of its species and without human company."† In this example the human being irre-

For additional information see Moltz, H., Imprinting: empirical basis and theoretical significance. *Psychological Bulletin* (1960), *57*, 291–314.

*Companionship in bird life, in C. H. Schiller (Ed.), *Instinctive Behavior* (New York: International Universities Press, 1957), p. 102.

†*Ibid.*, p. 105.

versibly acquires the capacity to elicit the "following" response and certain patterns of vocal behavior. The acquisition of this capacity—eliciting innate behavior patterns—by a stimulus is believed to be possible only during a critical period, usually a day or two following hatching.

The purpose of this exercise is to investigate the process of imprinting in the young Peking duck (*Anas platyrhynchos*). A moving visual stimulus will be presented to a duckling and we can study the effects of this stimulus on two dependent variables: (1) the degree to which the duckling follows the stimulus and (2) the frequency of "distress" calls.

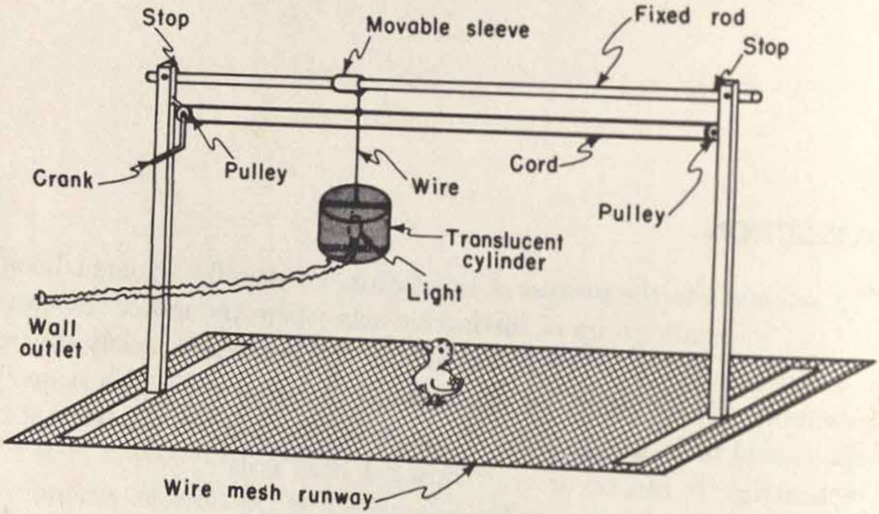


FIGURE 18-1. Imprinting apparatus.

APPARATUS

An imprinting runway with a wire mesh floor (see Figure 18-1) will be provided for each pair of students. The runway is constructed so that the experimenter, by turning a small crank, can move a transilluminated cylinder (the imprinting stimulus) continuously back and forth along it. The color or brightness of the imprinting stimulus can be altered by changing the color or the number of light bulbs inside the cylinder. Its height above the floor can be adjusted by lengthening or shortening its wire supports.

SUBJECTS

Two Peking ducklings will serve as subjects for each pair of students. Each duckling has been housed individually in an environment that contained no moving visual objects. One of each pair of ducklings will have been imprinted to the cylinder prior to the experiment; the other not. Information on their past histories and their ages will be available.

Ducklings are fragile organisms. Handle them as little as possible and with care.

PROCEDURE

Each pair of students should follow the instructions of Part A and either Part B or Part C.

Part A. Acquisition of the "Following" Response. Place two low-wattage white light bulbs in the imprinting cylinder and adjust its height to 2 to 3 in. from the floor. Before beginning the experiment, practice moving the stimulus at a speed of about ½ ft per sec.

Turn off the room lights and place the "naïve" duckling in the middle of the runway. Begin moving the stimulus immediately at about ½ ft per sec. Alternate 3-min periods of movement with 1- or 2-min periods of rest, keeping the duckling in the vicinity of the apparatus. Record the amount of time the duckling follows the imprinting stimulus in each 3-min period. The duckling is considered to be following when it moves in the same direction as, and is within 8 in. of, the cylinder. Also record the frequency of distress calls, indicating whether or not they occurred during the "following" response. Distress calls are loud, high-pitched chirps, easily distinguished from the soft, more frequent, low-pitched chirps. Continue this procedure for at least 30 min.

Part B. Stimulus Generalization. Select a dimension along which the stimulus can be easily varied, for example, brightness, speed of movement, height, or color. Arrange the equipment so that changes in the stimulus along the chosen dimension can be made quickly.

Place in the apparatus the duckling that had been imprinted prior to the experiment. Present the imprinting stimulus with two white light bulbs at a speed of ½ ft per sec. Alternate periods of movement with periods of rest as before, but this time cover the duckling with a small cardboard box during rest periods. Continue this procedure until the following score has stabilized.

Next, during each rest period, while the duckling is covered, change the stimulus to a new value on the chosen dimension and determine the following score for the altered stimulus. Continue this procedure as long as possible, occasionally retesting with the original value of the stimulus.

Part C. Control of the Following Response by a Stimulus Other Than the Imprinting Stimulus. Follow the instructions for the study of the acquisition of the following response (Part A) with two modifications. Use yourself as the imprinting stimulus (walk up and down the runway) and substitute a previously imprinted duckling for the naïve duckling.

RESULTS

For Part A plot the following score and the number of distress calls emitted as a function of successive 3-min intervals. Divide the number of distress calls emitted during following by the total number of distress calls for successive 3-min periods. Plot the results. For Part B compute the mean following score and the mean number of distress calls emitted for each value of the stimulus employed in the generalization tests. Plot these averages as a function of the value of the stimulus. For Part C compare the acquisition of the following response to the second imprinting stimulus with the acquisition of the following response to the first stimulus.

Report any important observations of the duckling's behavior.

DISCUSSION

Analyze the variables involved in this experiment. Is there any relation between the two dependent variables? How high would a following score have to be before one could say that it did not arise from random walking? What is the independent variable?

Discuss, on the basis of the experimental evidence, these characteristics of imprinting proposed by Lorenz:

1. A stimulus can be imprinted *only* during the first day or two following hatching.

2. Once a stimulus acquires the capacity to elicit the following response, it becomes the only, or at least the preferred, stimulus for eliciting the response.

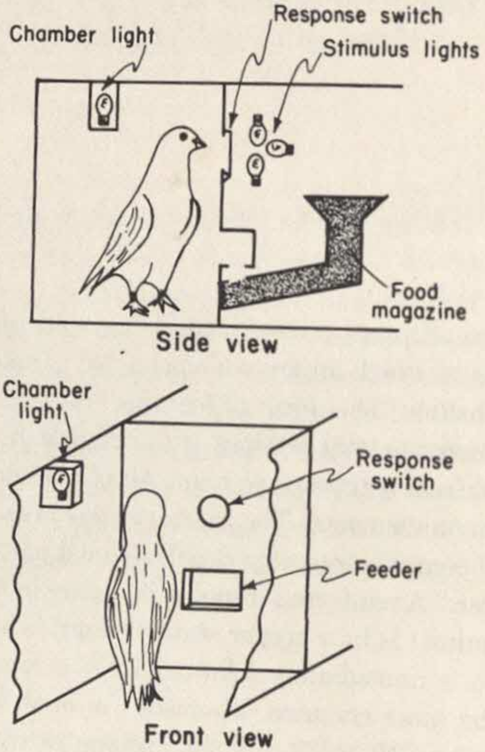
Introduction to Chapters 19 to 23

The next five chapters present experiments on operant conditioning, a type of learning in which an animal's behavior is modified by the consequences of its behavior. This form of learning has been demonstrated in a large variety of experimental settings with animals ranging up and down the phyletic scale from octopuses to man. All of these demonstrations contain certain common elements. The animal's movement always operates—hence the word "operant"—on some clearly defined part of the environment, called a "reinforcer." A reinforced response increases in its rate of occurrence, but only if the animal is in a proper state of deprivation for the reinforcer and the response is immediately followed by the reinforcer.

Although the most common laboratory animal is the white rat, the exercises in Chapters 19 to 23 call for pigeons as experimental subjects. The pigeon has a number of advantages over the rat as a psychological subject. It lives longer, is less prone to disease under laboratory conditions, is easier and less hazardous to handle since it lacks teeth, and is more sensitive to visual stimulation, which is the most inexpensive and convenient form of energy to use in the elementary laboratory. As far as intelligence is concerned, the pigeon is certainly no worse than the rat, and perhaps slightly better. If, however, your laboratory uses rats, you will find these exercises suitable with only minor modifications.

For additional information see pp. 14–32 in Ferster, C. B., and B. F. Skinner, *Schedules of Reinforcement* (New York: Appleton-Century-Crofts, 1957).

The reinforcer used in these experiments is food. Each time the pigeon is reinforced, it is given access to a tray containing a mixture of various kinds of grain (usually kafir, vetch, and hemp seed) for about 3 sec. The effectiveness of this reinforcer is guaranteed by keeping the pigeon at 80 percent of its normal weight. The initial deprivation of the pigeon should be accomplished gradually, by feeding it about 3 to 5 gm daily, rather than by total starvation. The pigeon should be weighed at least every other day and, if its weight is below the 80-percent level, fed an amount of grain equal to the deficit below 80 percent. A pigeon should never be fed just before an experiment. The standard automatic feeding device used in these experiments allows the pigeon to consume approximately ¼ gm of feed in each 3-sec cycle. A typical pigeon consumes about 60 such reinforcements in a session before showing any significant effects of satiation. If your feeder differs from this, you will have to take account of the difference in planning and interpreting your experiments.


OPERANT-CONDITIONING APPARATUS.

Side view

Front view

The most convenient form of behavior to be studied in a pigeon is its pecking response. The standard experimental chamber is shown in the accompanying figure. The chamber is equipped with a hinged switch mounted on a wall at about beak level, which is 7 to 8 in. for most pigeons. The pigeon's view of the switch is of a circular disk, measuring about ¾ in. in diameter and made of a translucent plastic. When the pigeon strikes the disk with a force of no less than 15 gm, a pair of electrical contacts is broken momentarily and an electrical circuit is triggered. In principle, the main reason for using electrical devices is the convenience to the experimenter, since an attentive observer can take the place of the circuitry. In practice, however, a good deal more than convenience is involved. The reaction time of a human operator inevitably delays, and therefore weakens, the reinforcer. Also, the use of a hinged switch with electrical contacts assures a constant criterion for an effective response. A human operator would find it virtually impossible to maintain a stable criterion without some sort of mechanical help. And, of course, an electrical circuit is free of the limitations imposed on the human operator by his having only two hands.

Behind the hinged switch, a few colored light bulbs, of the type used on Christmas trees, are used as the stimuli in the experiments. The bulbs are turned on and off either automatically by a circuit or manually by switches. The disk is transilluminated by these bulbs. Finally, the experimental chamber should have an additional source of illumination, one that does not transilluminate the disk.

If you are using rats instead of pigeons, the hinged switch should be replaced by a lever, one end of which protrudes into the experimental chamber and can be operated by a force of not more than 25 gm. The rat depresses the lever, thereby operating either an electrical circuit or the human observer. The feeding device, too, has to be modified since the rat's normal diet differs from the pigeon's. A large variety of laboratory foods for rats and automatic devices for delivering them are available. The major requirement of any feeder is that it present a small but consistent amount of food. If you are using adult rats more than 120 days of age then a 60-percent level of deprivation is required. Younger rats cannot tolerate this severe a deprivation, but they are not very satisfactory as subjects in any case. Since rats do not have color vision, the use of various colored lights is not appropriate. One alternative is to put several bulbs at different places in the chamber and use their location as the distinguishing feature of the stimuli. A better, but much more expensive, alternative is to use tones of various frequencies.

19

Basic Operant Phenomena: Acquisition, Continuous Reinforcement, Extinction, and Spontaneous Recovery

This experiment introduces two basic phenomena of operant conditioning. The first of these is the increase in the frequency of behavior that is regularly followed by a reinforcer. The second is the decrease in the frequency of such behavior after reinforcement is discontinued.

In operant conditioning, as distinguished from Pavlovian or classical conditioning, the animal's behavior is instrumental in producing the reinforcer. The experimenter can select virtually any movement and bring it under the control of the reinforcer by arranging that the one is regularly followed by the other. But this does not mean that operant conditioning must always deal with movements that are already being made by the animal. New movements, or novel sequences of movements, may be formed by a process of approximation. For example, a pigeon can be taught to turn a somersault, which is not ordinarily part of a pigeon's repertory of movements. First, downward movements of the head are reinforced; then, after the pigeon has learned to keep its head near the floor, movements toward the rear are reinforced. Eventually, the physical characteristics of the bird's new posture guarantees a somersault, a movement which, in turn, receives reinforcement. By using successive approximations, an ingenious trainer can thus mold, or "shape," highly unlikely movements. In these exercises, however, we will be shaping and observing more conventional modes of behavior.

For additional information see pp. 65–81 in Skinner, B. F., *Behavior of Organisms* (New York: Appleton-Century-Crofts, 1938).

PROCEDURE

Magazine Training. To insure immediacy of reinforcement, the pigeon must first be trained to make a rapid and positive response to the operation of the feeding device. Most such devices are electrically operated and are somewhat noisy, thus providing a signal to the animal of the availability of food. If you are using a silent feeder, it is a good idea to add some sort of signal, such as a rap on the outside of the chamber. A pigeon may be considered magazine trained when it approaches the magazine rapidly at times of operation and rarely at other times.

A few minutes after placing the pigeon in the chamber, which should be illuminated, operate the feeder. The noise may at first startle the pigeon and inhibit any movement, but continue to operate the feeder until the pigeon approaches and eats. A badly frightened pigeon can often be helped by scattering a few grains of food around the floor in the vicinity of the feeder. The feeder should be operated for its normal 3-sec cycle at irregular intervals averaging about 15 sec, until the pigeon's response to it is rapid and positive regardless of where in the chamber the pigeon is when the feeder is operated. Since the presentation of food is a potent reinforcer for a hungry pigeon, the student should be careful to avoid conditioning irrelevant behavior. The pigeon should be in various parts of the chamber, doing different things at successive operations of the feeder. Successful magazine training should be completed within 15 to 20 reinforcements, not counting those initial operations of the feeder before the pigeon had begun to eat.

Training to Peck the Key. If you are using automatic equipment, adjust it so that any pecking on the response key will operate the feeder for the 3-sec cycle. For nonautomatic reinforcement, be ready to give the reinforcer manually as soon as the key is pecked. Instead of waiting for the pigeon to peck the key, you can speed matters by reinforcing successively closer approximations to this behavior. Exactly how this is accomplished depends upon the behavior of the particular pigeon. For example, one may begin by reinforcing only when the pigeon is in front of and facing the key, which should be transilluminated with a white light. This will increase the frequency with which the pigeon assumes this position. Then reinforcement should be withheld until there is a movement of the pigeon's head, however slight, toward the key. Gradually, the extent of this movement should be increased by selective reinforcement. Finally, the pigeon's beak will strike the key, at which time reinforcement will be immediately delivered, either automatically or manually.

Maintenance by Continuous Reinforcement. Reinforce the first 20 pecks. One useful way to record the behavior is to note at the end of each 10-sec period the number of pecks since the first one. Do not include the duration of the feeding cycle in the measurement of the 10-sec periods. A graph of this number as a function of time gives what is called a "cumulative record." Since every peck is being reinforced, and since there are to be exactly 20 reinforcements given during this phase of the experiment, the cumulative record must rise to a total of exactly 20, if the pecks occurring during the feeding cycle are omitted. A cumulative record is useful for showing how the pigeon's rate of pecking may have changed in successive 10-sec periods.

Extinction. After the twentieth reinforced peck, discontinue reinforcement, but continue to record the pecking as before and make notes on any changes in the pigeon's general behavior.

Spontaneous Recovery. After the frequency of pecking has fallen to fewer than one peck in 30 sec, turn off all of the illumination in the chamber for 3 min. Pigeons do not normally peck in the dark. Then, turn on both the light behind the key and the overhead lights and record whatever pecking occurs in 5 min. Finally, repeat the procedure of turning off all illumination for 3 min and once again record the number of responses in a 5-min period.

RESULTS

Plot the cumulated number of pecks as a function of time under each of the experimental conditions. Compare the rates of responding under the various experimental conditions. Note any marked changes in behavior, other than in the actual key pecking, during the periods of extinction.

DISCUSSION

Did the physical characteristics of the pigeon's key peck depend in any specific way on the stages in the original successive approximations to it? Are there any implications here for the understanding of operant conditioning? Discuss the factors that may be involved in the speed with which the pigeon was originally trained, and the speed with which extinction took place. What does spontaneous recovery say about the process of extinction? Is extinction a mere unlearning of what was learned? Is the rate of responding a satisfactory measure of the behavior in this experiment? Discuss the shortcomings, if any. What may account for an increase in response frequency at the beginning of extinction?

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Successive Discrimination

A response that is reinforced only in the presence of a stimulus and not in its absence will occur more often when the stimulus is present than when it is absent. A stimulus that acquires this kind of control over behavior is a "discriminative stimulus." The student already encountered such stimuli in the previous experiment when he trained the pigeon to go to the feeder. The behavior involved in going to the feeder was reinforced only in the presence of the various stimuli that accompanied the feeder's operation, and the pigeon learned to approach at such times and not at others. In this experiment, we will study in quantitative detail the formation of another discrimination, one between the two colors red and green, with which the response key can be transilluminated. At first, the pigeon is to be reinforced for pecks that occur when the key is alternately red and green, so that the response becomes approximately indiscriminate with respect to color. Then, when reinforcement is correlated with only one of the colors, the pigeon will learn a discrimination between the two colors.

The discrimination manifests itself as a gradually increasing difference between the rates of responding in the presence of the two stimuli. The difference is due not only to a decline in the unreinforced pecking, but also to an increase in the rate of pecking in the presence of the stimulus that continues to be associated with reinforcement.

For additional information see pp. 582–599 in Woodworth, R. S., and H. Schlosberg, *Experimental Psychology*, rev. ed. (New York: Holt, Rinehart and Winston, 1954).

PROCEDURE

In this experiment, pecks are reinforced only intermittently, so that large samples of behavior may be observed before the pigeon becomes satiated with food. The reinforcements should occur at variable intervals of time, averaging 1 min and ranging from about 5 sec to 2 min. Before the experiment begins, prepare a series of 10 different time intervals in irregular order and averaging 1 min. Reinforcements should be delivered only for the first peck after the end of each one of these time intervals. At the end of the series of 10 reinforcements, start over again. This schedule of reinforcement, it should be noted, prescribes the minimum, and not the actual, intervals between successive reinforcements. The actual intervals between reinforcements may be much longer, if the pigeon should stop pecking for substantial periods of time.

The most convenient way to program an intermittent schedule is automatically. Even a semiautomatic arrangement is considerably better than a purely manual one. For example, it is possible with just a few electromagnetic relays to wire a circuit that can, by depressing a push button at the end of each interval in the series, be primed so that the next peck will operate the feeder.

The experiment should start with 20 reinforcements on the intermittent schedule, 10 for pecking at the red key light and 10 for pecking at the green key light. This phase of the procedure should last approximately 20 min, given the schedule of reinforcement. Next, alternate 2-min periods of red and green, reinforcing intermittently in the presence of the red stimulus and not reinforcing in the presence of the green. Continue the alternation until pecking either ceases in the presence of the green stimulus or falls to a low and apparently unchanging level.

The discrimination just formed should next be reversed by discontinuing reinforcement in the presence of red and restoring it in the presence of green. This, too, should be continued until the responding at the red light falls to some low and stable level. Finally, discontinue reinforcement altogether, allowing extinction to progress until there is less than one response in 30 sec, or until the laboratory session terminates.

Continue to record responding as in the previous experiment—that is to say, cumulatively in 10-sec periods. Two such tallies should, however, be kept, since the responding in the presence of the red and green lights should be cumulated separately. Keep track of the order in which these numbers are collected, so that it will be possible to recombine them later.

RESULTS

Plot the cumulated number of pecks as a function of time in the presence of each stimulus before, during, and after the formation of the discrimination, during the reversal of the discrimination, and throughout the final period of extinction. Also plot the total number of pecks cumulatively by combining the two tallies into a single cumulative record, during the successive experimental conditions.

DISCUSSION

Discuss the role played by the process of extinction in the formation of a discrimination. Is there any evidence in the data that something more than extinction is involved in discrimination learning? If the pigeon failed to learn a perfect discrimination in that it continued to respond in the presence of the stimulus not associated with reinforcement, describe any salient features of the incorrect behavior. What may account for this incorrect responding and what steps might be taken to eliminate it? Compare the decline in responding during discrimination training and during the final extinction period. Try to account for any differences. Discuss any changes in responding that may have occurred in the presence of the stimulus associated with reinforcement during the initial discrimination training or during the reversal. It has occasionally been said that the study of sensation is equivalent to the study of discriminative stimuli and the responses they elicit. Discuss.

21

Conditioned Reinforcers and Chained Schedules of Reinforcement

A stimulus that initially has no consistent influence on behavior can become a reinforcer if it is paired with a primary reinforcer such as food. Such an acquired reinforcer is called "conditioned," or "secondary," and is exemplified by the discriminative stimuli that accompany the operation of the feeding device in all of these experiments.

When the pigeon pecks at the key and its behavior is reinforced, there is a chain of responses and stimuli. The key peck triggers the feeder, producing a set of discriminative stimuli, which, in turn, make the pigeon approach the food. The sight of the food serves as yet another discriminative stimulus in the chain, one that elicits the behavior of seizing and ingesting the food. It could be shown experimentally that each of the discriminative stimuli in the chain is itself a reinforcer which could be used in isolation from the rest of the chain to increase the frequency of a new response. For example, after a pigeon has been magazine trained, the sound of the feeding device alone can be used as a reinforcer for some new response, such as operating a lever. Although such demonstrations of conditioned reinforcement have been done, they suffer from a handicap that makes them inappropriate in an elementary laboratory. Since conditioned reinforcers derive their potency from pairings with primary reinforcers, they quite naturally lose their potency when they are presented in isolation. Every presentation of the conditioned reinforcer without the primary reinforcer is, in effect,

For additional information see pp. 197–208, 231–247 in Keller, F. S., and W. N Schoenfeld, *Principles of Psychology* (New York: Appleton-Century-Crofts, 1950).

an extinction trial for conditioned reinforcement. If this extinction should take place too rapidly, the new response may not show a measurable increase in frequency. In order to avoid this problem, this exercise will demonstrate conditioned reinforcement within the context of an intact chain of responses and stimuli.

A blue light projected through the response key will serve as the conditioned reinforcement. At first, the pigeon's behavior is reinforced by food for pecking when the key is blue. Then, the color will be changed to red, in the presence of which pecking changes the color back to blue. Pecking at blue produces food as before. The sequence of events may be viewed as a chain, one in which the red light is a discriminative stimulus for pecking that is reinforced by a change in the color of the key from red to blue. The blue light is, however, itself a discriminative stimulus for pecking, but it is a discriminative stimulus for pecking that is reinforced by the primary reinforcer, food.

By itself, this procedure would not prove that the blue light is a conditioned reinforcer, since the same kind of behavior occurs in both links of the chain and one could argue that all the behavior is being maintained by the primary reinforcer alone. To answer this reasonable objection, the procedure adds a final step in which pecking is the appropriate behavior during the first link, but not during the second. Under these conditions, it becomes clear that the behavior in the two links of the chain is under the control of separate reinforcers.

PROCEDURE

The procedure has four steps.

1. Reinforce pecks on the blue key according to a variable-interval schedule, as in the previous experiment, but with an average interval of 30 sec instead of 1 min. Fifteen such reinforcements should be given.

2. Following the fifteenth reinforcement, change the key color to red and let the second peck change it back to blue. Reinforce a peck with food at the end of the time interval dictated by the variable-interval schedule and, at the same time, change the color to red. Repeat the cycle, using the next time interval of the variable-interval schedule when the light is blue. Continue repeating the cycle until the pigeon has received food five times.

3. Increase in steps of one the number of pecks required to change

the key color from red to blue. Stop increasing the requirement when it reaches 10 pecks, and then give 12 more cycles with the requirement held constant. The food should be given on the same schedule as before.

4. In this final stage of the experiment, reinforce the pigeon with food only if it refrains from pecking in the presence of the blue light. Ten pecks are still required to change the color from red to blue, but then the feeder is operated as soon as the pigeon allows 5 sec to go by without pecking. Each peck starts the 5-sec period anew. As in the earlier stages of the experiment, the color changes to red as soon as the pigeon gets fed. If the pigeon succeeds in mastering this task before it becomes satiated with food, the delay should be increased to 10 sec. The student should not expect the pigeon to stop pecking entirely during the second link of the chain, but rather to slow down to a very low and stable level.

RESULTS

Prepare cumulative records of the results for each procedure, always distinguishing between pecks on the red key and pecks on the blue key. Compare the rates of pecking on the red key during the various phases of the experiment.

DISCUSSION

Discuss the necessary and sufficient conditions for establishing a conditioned reinforcer in view of your own observations. Explain why it is important to be able to distinguish between the behavior during the two links of the chain in order to demonstrate that the blue light is a conditioned reinforcer. What information is there in the data to suggest how the strength of a conditioned reinforcer can be experimentally varied? What kind of behavior is being reinforced when the pigeon is taught to refrain from pecking?

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Schedules of Reinforcement

A schedule of reinforcement is a rule that states when a response is to be reinforced. A schedule may call for a certain number of unreinforced responses, or a certain time without reinforcement, or any combination of number and time.

Schedules based upon the number of responses are called "ratio schedules," and those based on time are called "interval schedules." Ratio and interval schedules are either "fixed" or "variable" according to whether or not the number or time specification changes from reinforcement to reinforcement. There are, then, four basic schedules:

1. Fixed-ratio (FR) schedules reinforce the first response after a fixed number of unreinforced responses.
2. Variable-ratio (VR) schedules reinforce the first response after varying numbers of unreinforced responses.
3. Fixed-interval (FI) schedules reinforce the first response after a fixed period of time without a reinforcement.
4. Variable-interval (VI) schedules reinforce the first response after varying periods of time without a reinforcement.

Ratio schedules are identified by a number signifying the ratio between responses and reinforcements. A fixed-ratio schedule of 10 (FR 10) means

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For additional information see pp. 100-111 in Skinner, B. F., *Cumulative Record*, enlarged ed. (New York: Appleton-Century-Crofts, 1961).

that every tenth response is reinforced. VR 10 means that the average ratio is 10. Interval schedules are specified by the minimum time between reinforcements. Thus, FI 10 min means that the reinforcement is given for the first response after 10 min without a reinforcement. VI 10 min consists of a set of minimum times between reinforcements whose average is 10 min.

An example of a schedule based upon a combination of time and number is the differential reinforcement of low rates of responding (DRL). On this schedule a response is reinforced only if it follows the immediately preceding response by not less than a specified interval of time (10 sec, say). Stated differently, a rate of not more than one response per 10 sec is required for reinforcement.

Each schedule of reinforcement has a particular effect on behavior, most easily seen by comparing cumulative records of responding on different schedules. A fixed-interval schedule generates a low rate of responding immediately after reinforcement and an increasing rate of responding as the time approaches after which the first response will be reinforced. A variable-interval schedule, on the other hand, may generate a nearly constant rate of responding throughout the intervals between reinforced responses. Fixed-ratio and variable-ratio schedules generally produce high, constant rates of responding. A very low rate of responding prevails on a DRL schedule.

In the present experiment, the experimenter will reinforce key pecks on several different schedules of reinforcement—FR, VI, and DRL.

PROCEDURE

As in the previous experiments, the most satisfactory way of arranging schedules of reinforcement is with automatic equipment. Even a simple circuit activated by a manual push button will help considerably. In either case, be sure that the circuit is designed to deliver the reinforcement at the *onset* of the response and not during the course of or after the designated response.

The response key and the experimental chamber are to be illuminated continuously throughout this experiment.

Fixed-Ratio Schedule. Reinforce every fifth peck until the pigeon receives four reinforcements. Then, increase the size of the ratio in steps of 10 up to FR 45, giving 4 reinforcements at each step, for a total of 20 reinforcements. If the pigeon "strains"—pauses irregularly for periods exceeding 2 min—decrease the ratio by 10 pecks for an additional few reinforcements.

Variable-Interval Schedule. With no break in the procedure, or change in stimuli, begin to reinforce pecking on a variable-interval schedule with an average interval of 30 sec and a range of intervals going from 5 to 90 sec. After 15 reinforcements, abruptly increase the value of the variable-interval schedule to 2 min by multiplying the intervals by a factor of 4 and give 15 more reinforcements.

DRL Reinforcement. Change abruptly from the variable-interval schedule to reinforcing responses only if they follow the preceding response by 10 sec or more, and give 10 reinforcements. Finally, extinguish the pecking at the end of the experiment.

RESULTS

Present cumulative records for the entire session. As in the previous experiments record over 10-sec intervals except where the prevailing rate of responding clearly justifies a longer or a shorter interval. Mark clearly the start and the end of each schedule of reinforcement and the occurrence of reinforcements.

DISCUSSION

Discuss the variables that control responding on each of the schedules investigated. Explain the difference in the rate of responding maintained by fixed-ratio and by variable-interval schedules. What further experiments could be done to test your explanation? What causes the changes in performance after changes in the schedule of reinforcement?

In what portions of the experiments can the behavior of the animal properly be described as learning? What processes other than learning seem to be involved? Describe and discuss.

What significance for theories of extinction attaches to the performance of the organism under extinction following reinforcement on a DRL schedule?

What are the theoretical and practical implications of the sensitivity of animals to schedules of reinforcement?

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Control of Behavior by Proprioceptive Discriminative Stimuli: A Mixed Fixed-Ratio, Fixed-Interval Schedule of Reinforcement

Multiple schedules of reinforcement and mixed schedules of reinforcement are alike in that they are both compounded of simple schedules of reinforcement. For example, in a given experiment the animal may at one time receive reinforcement on a variable-interval schedule and at another time on a fixed-ratio schedule. Mixed and multiple schedules are different in that a multiple schedule employs special stimuli that are correlated with each of the separate, component schedules, but a mixed schedule does not employ such stimuli. For example, a red light might be used as the stimulus associated with the variable-interval schedule, and a blue light (or simply no light at all) with the fixed-ratio schedule. Because the lights do not depend upon the behavior of the organism and are external to the organism and because they mark the two component schedules, we call such a combination a "multiple schedule." The stimuli in a multiple schedule are, in effect, discriminative stimuli that elicit responding appropriate to the particular simple schedules correlated with their presence.

Mixed schedules are characterized by the absence of special stimuli to mark the transitions from one component of the schedule to the other. But despite their absence, the organism may come very close to performing appropriately to the schedule in force at a given time. For example, if a fixed-interval (FI) of 3 min is alternated irregularly with a fixed-ratio (FR)

For additional information see pp. 197–208, 231–247 in Keller, F. S., and W. N. Schoenfeld, *Principles of Psychology* (New York: Appleton-Century-Crofts, 1950); see also pp. 100–111 in Skinner, B. F., *Cumulative Record*, enlarged ed. (New York: Appleton-Century-Crofts, 1961).

of 50 responses, without any stimuli correlated with the two schedules, a pigeon's responding may nevertheless accelerate typically through most of the fixed-interval schedule and be rapid and steady in the fixed-ratio schedule. This result comes about because the bird's own behavior can act as a discriminative stimulus—an internal or a "proprioceptive" one—to control the responding. The records obtained under such a mixed FI-FR show that the pigeon characteristically emits a series of responses at a high rate (appropriate to the ratio) just after every reinforcement. When the interval schedule is in effect, this series of responses is not reinforced and the pigeon shifts to the performance that is appropriate to the fixed-interval schedule, first pausing and then accelerating. The discriminative stimulus for the fixed-ratio responding is the reinforcement itself. The discriminative stimulus for the fixed-interval performance is the series of about 50 unreinforced responses at a high rate.

The present experiment studies the control of a pigeon's behavior by its immediately preceding behavior. Pecking is to be reinforced on a mixed schedule composed of FR 10 and FI 2 min. The emission of 10 or more unreinforced responses just after reinforcement should come to be a discriminative stimulus for the typical fixed-interval pattern of responding.

PROCEDURE

Begin with 20 reinforcements for pecking on FI 2 min while the key is transilluminated by a white light. Then, without any delay in the procedure, give half of the reinforcements for the tenth peck after the preceding reinforcement (FR 10), and the other half on the FI 2 min. The key should continue to be transilluminated by a white light.

Do not allow any stimuli to be differentially correlated with the different schedules. Alternate the FR with the FI irregularly, but be sure to have 5 of each for every 10 reinforcements. Each student should prepare his own series, as for example: FI, FR, FR, FI, FI, FR, FI, FR, FR, FI. Thirty reinforcements are to be given in this phase of the procedure. Employ a method of recording that will have sufficient refinement to reveal any consistent changes in behavior just after reinforcement.

Change the schedule from a mixed schedule to a multiple schedule by consistently correlating a different color of the key with the fixed-ratio schedule while continuing to use a white light for the FI. Record in a way that is effective in revealing changes in the performance.

RESULTS

Prepare the usual cumulative records to show the performance under each procedure. If it proved impossible to record accurately all of the time, then three or four typical examples of the performance under each procedure will be acceptable. Specify on the records the procedure used and the salient features of the behavior elicited.

DISCUSSION

Analyze the performance on the mixed schedule as a chain of behavior. List the relevant stimuli (discriminative and reinforcing) and discuss their nature. Why is it more difficult to control behavior with proprioceptive stimuli than with external stimuli? Is there any indication that proprioceptive stimuli are involved in the multiple schedule, as well as in the mixed schedule?

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